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ENCIRCLE YOUR CALENDAR — FEB. 26-MARCH 1, 1950 — HOUSTON MEETING

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OPINION

COMMENT

THE INSTITUTE-1950 MODEL

THE start of a new year, which is also the beginning of an Institute year, is a logical time to review the status of the Institute and to plan the year's operations. It is an excellent time to take an over-all view of the Institute's general situation.

Important facts concerning our present status are as follows:

1. Membership of the Institute is still increasing. From Nov. 1, 1948 to Nov. 1, 1949 the Active membership increased from 3313 to 3670, or 10.8%; Associate membership increased from 398 to 447, or 12.3%; and Junior membership increased from 5179 to 5594, or 8.0%. The over-all increase in membership was 8890 to 9711, or 9.2%.

2. A major activity of Council during 1949 was a study of the membership structure of the Institute. Results of the discussions have been incorporated in drafts of proposed constitutional amendments. In accordance with the constitution the drafts have been discussed at a business session of the Institute, and ballots covering five projected amendments are being submitted to the Active membership.

The first objective sought by the proposed amendments is to insure that the Institute covers adequately the entire chemical engineering profession, and recognizes chemical engineers of all types, from students to qualified professional chemical engineers. A second objective is to provide for admission as Associates men of nonchemical engineering training who are qualified to enrich our activities. A third objective of the proposed amendments is to simplify our election procedure.

3. The official publication of the Institute, namely, *Chemical Engineering Progress*, is well underway. The year 1950 will be the fourth for C.E.P. under professional full-time editorial and business management. It is the objective of C.E.P. to be the authoritative and recognized publication for high-grade technical and scientific articles in the chemical engineering field, and, at the same time, to carry the interesting and important news of the Institute, and of chemical engineering. To meet this twofold objective, advertising support has been solicited in order that the financial burden of the publication can be carried adequately without requiring unreasonable support from dues income.

4. The Institute conducts a well-rounded program of activities, primarily under organized committee action. The general standing committees that are responsible for the details of most Institute activities are: Admissions, Program, Chemical Engineering Education and Accrediting, Public Relations, Awards, Publication, Local Sections, Chemical Engineering Projects, Constitution & By-Laws, Student Chapters, Chemical Engineering Catalogue, Standard System of Symbols, Nuclear Energy, Professional Guidance, Industrial Waste Disposal, and Testing Techniques. Each of these committees has an active program, which is worked out by committee initiative under general guidance by Council.

5. The Institute is financially solvent. Because of the postwar inflation, the Institute operated in the red from 1946 through 1948. As a result of a rigid economy program and a realistic

financial appraisal of all Institute activities at the beginning of 1949, a small surplus over expenses was achieved during 1949. The 1950 budget, already approved by Council, also forecasts operation in the black.

6. The Institute has 50 Local Sections, has accredited 55 schools through its Accrediting Committee, and has 89 Student Chapters which have a membership of approximately 8000 students.

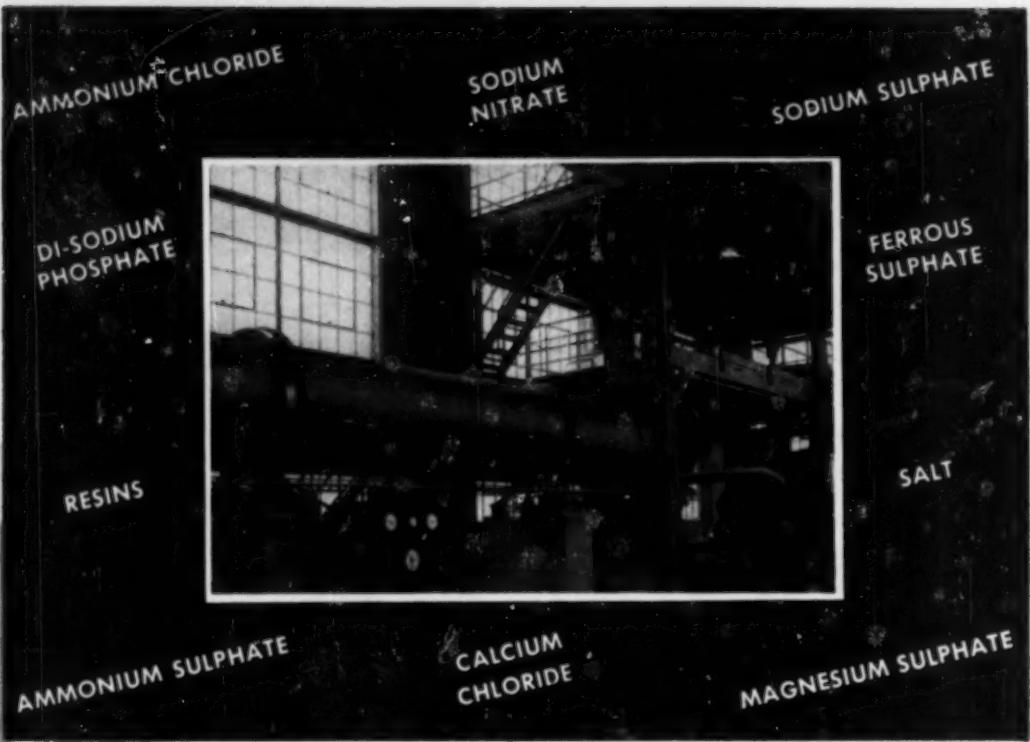
Such is the present situation. Plans for the immediate future may be forecast. The keynote of the year's activities should be "evolution but not revolution." Chemical engineering is growing, is extending its field of service, and is refining and improving its techniques. It is essential that the Institute lead, rather than follow, if it is to succeed in its mission of serving adequately chemical engineering. The proposed constitutional amendments represent one method of maintaining leadership. A second approach is through the labors of a Committee of Past Presidents, appointed by President Curtis during 1949, and which consists of George G. Brown, Lawrence W. Bass, and J. Leroy Bennett. To this committee has been assigned the task of planning the long-range future and basic policies of the Institute. It is expected that important conclusions and recommendations will be made by this Committee during 1950.

During 1950 the following specific lines of development should be emphasized: First, the Institute should energetically continue its development of high-grade professional and technical publications. Such activities should, in general, center around C.E.P. Proposals for the separate publication of symposia and groups of technical articles presented at Institute meetings and which cannot be published in C.E.P. are being considered. Second, dynamic committees should continue to strengthen the Institute influence in chemical engineering education, and to aid young engineers to grow professionally. Third, further improvements in meetings and program should be made. Fourth, public relations should be given aggressive attention to capitalize on the excellent beginning that has been done to date. Fifth, cooperation with other engineering groups should be maintained. Sixth, the local sections should be encouraged and aided and the formation of additional ones encouraged. Seventh, a newly appointed Membership Committee actively will stimulate qualified nonmember chemical engineers to apply for membership.

A word as to the financial philosophy of the Institute is in order. It is as follows: if the Institute correctly interprets the trends in chemical engineering and leads, rather than follows, an adequate financial status should follow automatically.

The newly elected officers and Council of the Institute assure the membership that they will do all in their power to carry forward the work of the Institute during 1950 in accordance with the objects that are stated in the Constitution: "the advancement of chemical engineering in theory and practice and the maintenance of a high professional standard among its members."

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ULTRASONICS—A NEW CHEMICAL ENGINEERING TOOL

DUDLEY THOMPSON

Virginia Polytechnic Institute, Blacksburg, Virginia

THE field of ultrasonics has been the subject of investigation for many years by scientists who have been primarily interested in theoretical aspects and bench-stage demonstrations of phenomena produced by this form of energy. In these investigations equipment for generating ultrasonic vibrations was the product of individual investigators.

Since the end of World War II, there has been a growing interest on the part of chemical engineers in the potentialities of ultrasonic vibrations as an industrial tool. This interest has included the development of equipment and methods which would permit the application of ultrasonics to chemical operations and processes in which this form of energy would improve the quality, quantity, and rate of production of the manufactured product.

This paper considers selected applications of ultrasonic energy to the field of chemical engineering. Four general methods of applying this form of energy are suggested: (1) as an analytical tool, (2) as an engineering tool, (3) as an extension of unit operations, and (4) as an extension of unit processes.

Analytical Tool

As an analytical tool, ultrasonics may be used to determine the mass of ions, to determine molecular properties, and to determine the average size of particles.

Mass of Ions. Debye (11) considered the application of ultrasonic waves to a solution of an electrolyte. If the dynamic reactions of ions of different masses are considered, the motion of the positive ions may differ from that of the negative ions. In turn, this means that periodically changing electric charge densities will accompany the sound waves. Debye (11) states that the potential difference produced may be measured. Consequently, definite con-

clusions may be drawn as to the masses of ions and from this the number of solvent molecules connected with them.

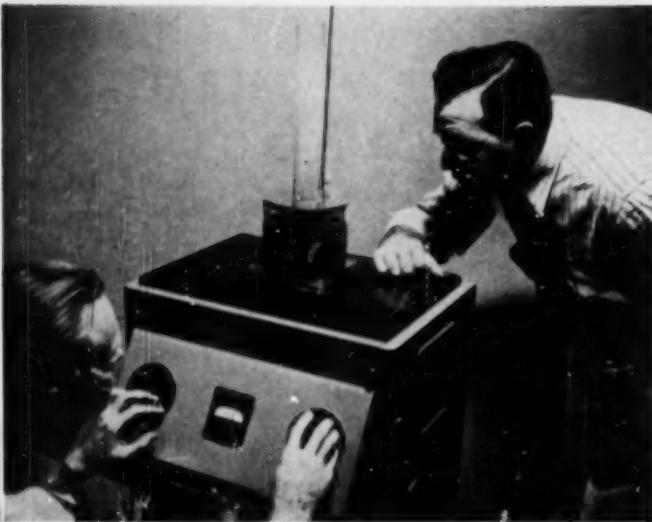
Molecular Properties. Application of weak ultrasonic waves in the investigation of molecular properties of fluids has been pointed out by Weissler (39). Specifically mentioned are molecular

weights of polymers, molecular volumes, temperature change of molecular association, adiabatic compressibility, and the ratio of specific heats of gases.

Size Determinations. Hermans (14-16), Pohlman (25), and others (6) have reported the orienting effect of low intensity ultrasonic fields on nonspher-



When ultrasonic waves coming from the air whistle and, focused on the base block, are reflected back on propagated wave, bits of cork can be held in suspension at the points of low pressure and high velocity.



To facilitate research in application of ultrasonics to industry, new ultrasonic generators are being developed. The transducer, which is on top of the power supply, operates in an oil-filled well. Power at 300, 500, 750 or 1000 kc. can be supplied by this instrument.

ical particles, the effect being proportional to the size of the particles. It is suggested that this effect may be used in conjunction with suspensions of particles of known size to ascertain the average dimensions of particles of an unknown size. Carlin (7) describes another application for determining size by means of ultrasonic vibrations. In this case a correlation is established between the amount of attenuation of ultrasonic energy and the grain size of a particular material such as an alloy.

Engineering Tool

As an engineering tool, ultrasonics may be employed in testing materials, measuring thickness, submarine signaling, and submarine detection.

Testing Materials. The industrial application of ultrasonics in testing raw materials, semifinished parts, and finished materials has been described by Carlin (8). Fatigue testing materials on an industrial scale have been reported in a similar manner.

Ultrasonic testing has been widely used for testing billets and other masses of steel, aluminum, brass, magnesium, and other materials. It has been used with good results on impeller wheels, drive shafts, and other objects where it was necessary to find flaws in the article prior to the final machining operation. Ultrasonic test-

ing has been used in testing propellers to see whether or not the internal reinforcements were correctly riveted and oriented, in testing bond between the silver coating on a bearing and the steel of the bearing, in testing bond of the cooling jacket in aeronautical engines, and in many similar applications. Ultrasonic methods are of particular value when used for locating fatigue failures. One example is the testing of locomotive axles and crankpins while they are in use on the locomotive.

The extent of this application of ultrasonics is readily appreciated when it is considered that "it is possible to shoot through 30 ft. of steel and find a small flaw."

Measuring Thickness. Ultrasonic testers (8) can be used to "measure wall thickness from one side by the reflection method." Although the pulsed ultrasonic tester can "directly measure the thickness of one-half inch of steel by transmitting a pulse into it and measuring the time between transmission and reception," the resonance method can "satisfactorily test the thickness of parts between about 0.005 and 0.5 in." The Sperry reflecto-gage is an instrument for measuring thickness by ultrasonic vibrations that is commercially available.

Submarine Signaling. Ultrasonic sub-

marine communication is of prime importance in wartime, although there has not been evidence of extensive use of this application at other times. It is suggested that the phenomenon of ultrasonic submarine signaling might be applied in a manner analogous to the photoelectric cell. The control of large volumes of liquid is indicated in which a change in the physical properties or the nature of the liquid would cause a change in an ultrasonic signal passed through the liquid.

Submarine Detection. The desire to perfect a method for applying ultrasonics to submarine detection supplied the impetus for Professor Langevin's pioneering investigations in France during World War I. Subsequently, considerable work has been done in other countries, including the United States. Underwater applications of ultrasonics have been extended to include depth-finding and the determination of submerged obstructions. It is suggested that the principles employed in submarine detection may find application in chemical engineering processing and storage of large quantities of liquids. Telemetering of quantities and rates as well as the detection of foreign substances are possible uses.

Unit Operations

As an extension of the unit operations, ultrasonics may be employed in the dispersion of solids, emulsification, distillation and extraction, crystallization, accumulation, separation, and coagulation.

Dispersion of Solids. Bergmann (4) called attention to the fact that many studies have dealt with the problem of ultrasonic dispersion of solids in liquids. Sollner (30) has pointed out, similarly, the peptizing action of ultrasonic waves on gels, gel-like substances, precipitates, and sediments. Nevertheless, the sound action is capable of dispersing only solid bodies of moderate cohesion. Patents have been granted on apparatus (40, 41) and on methods (31) for producing ultrasonic dispersion.

Emulsification. Wood and Loomis (43) recorded the phenomenon of emulsification in their pioneering paper on the effects of ultrasonics. Accounts have been given subsequently by many investigators of the emulsification of various immiscible liquids, mercury and water, and molten metals and water. Marinisco and Holtz (22) disclosed the application of ultrasonic emulsification to the perfume industry. Such emulsions avoided the use of organic solvents that

were harmful to the skin. Biske (4) claimed an improved fuel for internal combustion engines by emulsifying small quantities of water and water soluble compounds in hydrocarbons by means of ultrasonic waves. Either the promotion of easy ignition or anti-detonating properties was possible according to Biske.

Distillation and Extraction. In a patent assigned to Shell Development Co., McKittrick and Cornish (21) claim that in a distillation process wherein ascending vapors contact liquid reflux in a reflux zone and are simultaneously subjected to the direct influence of sonic vibrations of frequencies between 50 cycles and 5 megacycles/sec., increased efficiency of fractionation results. Application of ultrasonic waves to liquid-liquid extraction and other mass-transfer operations is also pointed out.

Crystallization. The rate of crystallization and number of centers formed are found to be increased in an ultrasonic field by Berlaga (2) and by Thompson and Cassady (9). The latter investigated the crystallization of alumina trihydrate from sodium aluminate solutions of the type used in the American Bayer process. Wood and Loomis (43) reported also that in sodium hyposulfite solutions the type of crystallization and rate of growth were affected by ultrasonic vibrations.

Accumulation. Sollner and Bondy (32) have shown experimentally that accumulation occurs at the nodes of standing waves in an ultrasonic field if the dispersed substance is less dense than the medium, e.g., toluene in water, and at the antinodes if it is denser, e.g., quartz in water. Although no accumulation is expected in truly colloidal solutions, strong effects are predicted for emulsions and suspensions with microscopic particles. In standing waves gas bubbles will accumulate at the nodes, whereas in progressive wave systems the bubbles are driven away from the source of the sound.

Separation. Hiedemann and Brandt (17) have disclosed a method for separating suspended solid and liquid particles from melts and liquids by accumulating these particles in a system of standing waves. Particles are then removed from the zones of accumulation. Applications suggested by the authors include: clarifying spinning liquids and oils, removing admixtures from metallic or other melts, changing the viscosity of oils, and clarifying emulsions.

Coagulation. The coagulating effect



Right: In test tube is water with mercury at bottom. Left: Mixture of two resulting after ultrasonic waves have dispersed mercury. Waves, with frequencies as high as 1,000,000 vibrations/sec. break up the mercury globule into millions of minute droplets, and disperse them evenly through the water. This homogenized mixture will last for many hours if undisturbed.



Quartz crystals vibrate when a voltage at high frequency is applied across them; ultrasonic waves are generated by the vibrating crystal. The crystal shown is one used in an ultrasonics generator built for use in industrial, biological, chemical, and physical fields. Frequency of the waves generated varies with crystal thickness.

of the micellar organism paramecium observed by Wood and Loomis (43) was at first thought to be a biological effect. However, the same effect was produced on wet sawdust (43) and later on powdered coal (42). Coagulation has been observed in liquid systems of dispersed quartz, oil, mercury, gas bubbles, and benzene (32), silver iodide (15), and phosphate tailing (36). Coagulation of aerosols (10) is easily achieved in an ultrasonic field and has been intensively investigated. Smoke and fog are inherently unstable and coagulate spontaneously. This phenomenon is

greatly accelerated by ultrasonics and is being operated on an industrial scale (10). Sonic collection installations have been employed in the coagulation of fog in a sulfuric acid plant of 300 tons/day capacity and the flocculation of soda ash from a paper mill recovery boiler.

Unit Processes

As an extension of the unit processes, ultrasonics may find application in oxidation, polymerization, depolymerization, electrolysis, and change of reaction rate.



Ultrasonic waves coming from a small air whistle are focused to a point of high intensity where they agitate the particles of cotton until they are ignited by heat of friction.

Oxidation. A chemical effect of ultrasonics that has been the subject of investigation of many scientists is that of oxidation (3, 5, 18-20, 26-29, 33, 37-38, 43). The process of cavitation is credited with activating the nitrogen of the air as well as the oxygen, resulting in the formation of hydrogen peroxide and nitrous and nitric acids. These substances, of course, would provide an oxidizing medium. It is suggested that ultrasonic oxidation may be employed to an advantage in certain cases to lower the pH, to provide an oxidizing medium, or both simultaneously. It is of interest to note the investigation of Solov'eva (33), who, from experimental work with frequencies of 394 kc., reports that ultrasonics catalyzes the oxidation of aqueous potassium iodide to potassium iodate and of ferrous sulfate to ferric sulfate by atmospheric oxygen.

Polymerization. Demann and Asbach (12) have shown experimentally that acetic acid may be polymerized to adol in an ultrasonic field of varying frequency. Experimental evidence is offered in the frequency range of 20 to 3,000 kc. Results show that increasing frequency and duration of the ultrasound yields more polymers but the best values were obtained by changing the frequency with progress of the reaction.

Depolymerization. On the other hand, Szalay (34, 35) has reported that highly polymeric molecules are split by means of ultrasonic waves. Using a frequency of 722 kc. on starch, gum arabic, and gelatin, Szalay found that depolymerization followed, which was measured by the change in viscosity and also isometrically with the starch solution. Slight decomposition of cane sugar to monosaccharides and of paraformaldehyde and hexamethylene tetramine was also found.

Electrolysis. Ultrasonic waves have been shown to eliminate overvoltage (24) and neutralize passivity (13) in solutions of electrolytes. Ripples are produced in cathodic electrodeposits (43, 44) and increases in the electrical conductivity (11) of water in an ultrasonic field have been demonstrated.

Reaction Rate. Initiation and acceleration of reaction rates under the influence of ultrasonic waves have been discussed by Weissler (39). Wood and Loomis (43) reported a "striking" acceleration of the "iodine clock reaction" as well as a difference in rate of growth of crystals in an ultrasonic field. Moriguchi (23) found that the formation of hydrogen in the reaction of zinc and hydrochloric acid was "markedly" pro-

moted as were other similar reactions. The rate of oxidation of potassium iodide and ferrous sulfate was reported by Solov'eva (33) to be increased with sound intensity, although the relation was not linear.

Chemical Engineering Requirements

Thus, it may be seen that the scope of phenomena produced in an ultrasonic field is extensive. In most cases qualitative explanations have been accepted although adequate quantitative data are still lacking. At the present time, unsatisfied requirements in the field of ultrasonics from the standpoint of the chemical engineer might include: (1) ultrasonic generators suitable for industrial research, development, and operation in various gaseous, liquid, and solid systems; (2) quantitative data of optimum conditions of frequency, intensity of ultrasonic field, time of irradiation, and other operating conditions; (3) accessory equipment; (4) methods; (5) technique; and (6) comprehensive and integrated literature. It should be pointed out that a number of industrial and institutional laboratories are reported currently active in exploring the field of ultrasonics, although little has been related concerning these endeavors. It is anticipated that the results of at least some of these investigations will be forthcoming in the near future.

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A CORRELATION OF PLATE EFFICIENCIES IN FRACTIONATING COLUMNS

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This report presents data, observations, and conclusions on the over-all efficiencies of a bubble-cap rectification column when operated with eight different binary distillation systems. Combinations were as follows:

- | | |
|---------------------------------|------------------------------|
| 1. ethanol—water | 5. acetaldehyde—water |
| 2. methanol—water | 6. acetone—water |
| 3. benzene—toluene | 7. methyl ethyl ketone—water |
| 4. benzene—carbon-tetrachloride | 8. toluene—pentane |

These represent a wide choice of systems, both in respect to chemical structure and physical properties.

All acceptable data were correlated according to the method proposed by O'Connell where over-all efficiency is a graphical function of the relative-volatility-viscosity product ($\mu\alpha$). Experimental data cover the range of $\mu\alpha$ from 0.2 to 40 with a corresponding efficiency range of 25%–80%.

Agreement of the correlation and the data varied with the system and conditions of the test. Low reflux ratios (up to 1.5) produced values in fair agreement, but high reflux ratios and/or stripping sections varied over a wider range. Evidence is presented which indicates that this effect is a function of L/V or some variable affected by it, although the effect is not a simple function.

Over the range of variables tested, the accuracy of the O'Connell correlation seems satisfactory for column design if normal reflux ratios are used and if the operation is not primarily of stripping character.

FOR many years, distillation has been a favorite subject for chemical engineering investigations. This interest has been fostered by the importance of the operation, and the variety and

intricacies of the problems. Attention has been paid to column fractionation with plates and bubble caps. Studies of size, shape, and placement of weirs, orifices, and bubble caps as well as that of number, size, and spacing of plates have consumed much time. Numerous mathematical analyses have indicated the number of ideal interchange units which would be necessary for any given separation, but unfortunately, when these

formulae have been put into use, they fail to encompass the mass of variables which affect the operation.

Attempts have been made to rationalize the discrepancies between the theory and industrial practice, and have resulted in a series of factors commonly known as plate efficiencies. If these factors were known for all systems and under all conditions, little more would be necessary; but they are all too few, and even when available, they appear to depend on the nature of the system, the type and nature of the column, and many other variables.

Effects produced by the physical properties of the components have been mentioned by early investigators. Walter and Sherwood (10) report the decrease of absorption efficiency with the increase in viscosity of the absorbent, and Keyes and Byman (4) agree on some effect in the distillation of an ethanol-water mixture. Drickamer and Bradford (2) aided in the work by publishing a correlation which was obtained by fitting a curve to a series of efficiency values from the analysis of numerous commercial columns, primarily of hydrocarbon components, and related only by the viscosities of the systems (Fig. 1). Evidence was presented (4) that the slope of the equilibrium curve affected the efficiency of the operation, and later a correlation of plate efficiency was presented (8) vs. the product of viscosity and relative

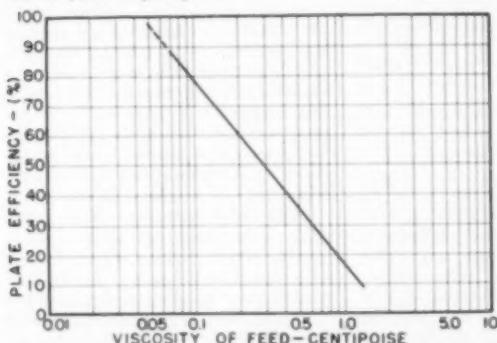


Fig. 1. Effect of viscosity on plate efficiency correlation of Drickamer and Bradford.

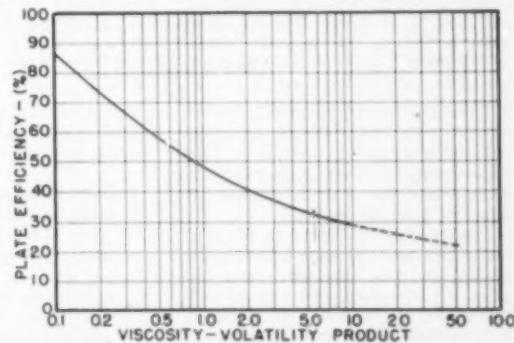


Fig. 2. Effect of viscosity-relative volatility product on plate efficiency correlation of O'Connell.

TABLE 3 General Properties of Systems.

| | Boiling Point Degree F. ^a | Viscosity in Centipoises (cP) | Relative Volatility (α) | Product ($\alpha \cdot \eta$) |
|-----------------------------------|---|----------------------------------|----------------------------|------------------------------------|
| 1. Ethanol - water | 73.6 + 100 | 0.5 + 0.6 | 0.7 + 11.0 | 0.5 + 6.5 |
| 2. Ethanol - water | 64.6 + 100 | 0.28 + 0.38 | 0.5 + 8.0 | 1.0 + 2.5 |
| 3. Benzene - Toluene | 80.1 + 110.7 | 0.28 + 0.29 | 2.3 + 2.6 | 0.6 + 0.6 |
| 4. Benzene - Carbon tetrachloride | 76.6 + 80.1 | 0.33 + 0.42 | 1.0 + 1.26 | 0.3 + 0.3 |
| 5. Acetaldehyde - water | 19.5 + 100 | 0.3 + 0.6 | 7.4 + 16.2 | 5.0 + 5.0 |
| 6. Acetone - water | 56.1 + 100 | 0.28 + 0.37 | 1.2 + 26.6 | 0.4 + 4.0 |
| 7. Methyl Ethyl Ketone - water | 73.8 + 100 | 0.25 + 0.25 | 0.4 + 35.0 | 10 + 10 |
| 8. Pentane - Toluene | 36.7 + 110.7 | 0.2 + 0.32 | 6.0 + 6.75 | 1.5 + 2.5 |

volatility. This last work was based again on the best curve drawn through a series of points which were obtained from published and unpublished data for a wide series of systems (Fig. 2). The curve was not fitted by an equation, and may be considered as an approximation for use when no more accurate data exist. This viscosity-relative volatility product has no direct physical significance and is not justified on strictly theoretical lines, although the form is suggested by a formidable series of supporting phenomena, which O'Connell relates.

Experimental Work. The column chosen for the investigation was a copper laboratory experimental unit with the following specifications:

| | |
|----------------------|---|
| Number of plates | 20 (plus reboiler) |
| Diameter | 10 in. |
| Plate spacing | .8 in. |
| Vapor risers | 1.625 in. diameter (4 per plate) |
| Downcomers | .50 in. diameter (2 per plate) |
| Weirs | .6 in. long \times 1 in. high (2 per plate) |
| Bubble caps | .25 in. diameter, \times 1.75 in. high (4 per plate) |
| Slots | .025 in. high \times 0.125 in. wide (31 per cap) |
| Calandria (Reboiler) | 12 in. diameter \times 12 in. high, with 24-1 in. diameter tubes. Steam on shell side, and with auxiliary open steam connection and external circulation tubes. |
| Feed pot | 6 gal. capacity, cut steam heated |
| Feed arrangement | feed delivered by gear pump through rotameter to alternate plates; 1, 3, 5, 17, 19 (from top) |
| Overheads | two tube and shell condensers in series, feeding a splitter box which was arranged to deliver any desired portion as either reflux to top plate, or to product tank, both lines contained rotameters. |
| Sampling | sample cocks arranged to deliver samples of liquid from exit over off plates 1, 3, 5, 17, 19. Samples of feed, waste, and overhead easily obtained. |
| Temperature | plate temperatures obtained by copper-constantan thermocouples placed in liquid on all plates. |

This column had previously demonstrated its ability to carry fractionations of benzene-toluene mixtures and ethanol-water mixtures with superficial vapor velocities of 1.25 ft./sec. and satisfactory plate efficiencies.

Data used by O'Connell in the original correlation (8) were within values of 27% and 90% plate efficiencies, and when the viscosities were expressed in centipoises, the viscosity-relative volatility product was between 0.10 and 7.5. It was desired in this investigation to extend the ranges if possible, to obtain

intermediate points, and to utilize systems which were somewhat different from those of the original plot. Mathematically, the same product may be obtained by the use of a low relative volatility and a high viscosity, or by the reverse condition. Practically, this situation is somewhat limited by restrictions of abnormalities, hazardous operation, poor analytical procedures, and similarity of components. Properties of the eight systems selected for this investigation are shown in Table 1.

A general outline of experimental procedure and method of evaluation of data was established in this investigation which was sufficiently flexible to accommodate the different systems and various conditions of operations. This

characteristics of the system being studied under stripping (high L/V) conditions

- Continuous fractionation, with the greater part of the column acting as a rectifier and feed near the bottom of the column. Data obtained from this type of run for the most part covered rectification characteristics, and correspondingly lower L/V ratios.

In preparation for a total reflux run, approximately 50 gal. of material was placed in the still feed tank. A quantity of the mixture was placed in the reboiler of the still so that the steam-heating tubes were covered. Cooling water was turned into the condensers and steam was admitted to the reboiler. Partial distribution of components was attained as vapors rose in the column, heating the entire column to operating temperature. As the vapor rose in the column and the liquid level in the reboiler fell, additional feed mixture was pumped into the column. The flow of feed was manually controlled to maintain the desired level in the reboiler, until condensed vapors re-entered the top of the column as total reflux. The feed was shut off and the column allowed to operate at total reflux until the column approached equilibrium conditions.

The approach of the column conditions to those of equilibrium was observed by taking thermocouple plate temperature readings at 10- to 15-min. intervals. When these readings became constant, it was assumed that the column had reached equilibrium. If, on total reflux runs, it was desired to adjust the range of component distribution, the change was made by the addition of feed and the removal of either distillate or waste.

The temperature of the liquid on each plate was recorded, later to be averaged for determining viscosity and relative volatility values in the column. Samples were withdrawn from alternate plates (1, 3, 5, 17, 19) and from the distillate and reboiler. These samples were usually about 25-30 cc. in volume and were obtained in the shortest possible time so that equilibrium conditions of the column would not be adversely affected. The quantity of distillate could be observed at any time during the operation by readings on a reflux rotameter.

Temperature measurements were made with copper-constantan thermocouples inserted in the liquid close to the center of each plate. The readings were direct with the use of a Leeds & Northrup automatically compensating potentiometer.

Continuous column operations were started in the same method as that for

procedure was used as a basis for four types of operations as follows:

- Total reflux operation
- Continuous over-all column operation, with feed near the center of the column and both rectification and stripping data being obtained
- Continuous fractionation with the greater part of the column under stripping conditions, and feed near the top of column. This type of operation gave data on the charac-

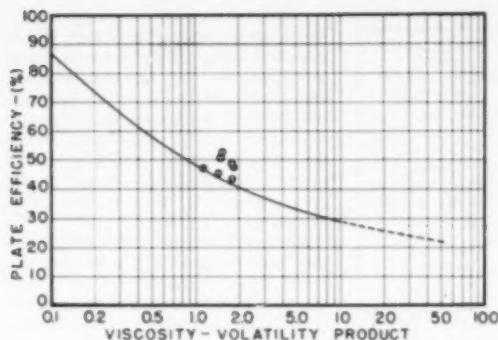


Fig. 3. Plate efficiencies for ethanol-water system.

total reflux runs. At the point where total reflux conditions would have been continuous, feed was introduced at a metered rate onto the plate containing a mixture most nearly corresponding to the concentration of the feed. The distillate was continuously split into product and reflux with the product rate adjusted to remove the proper amount of low boiler from the system at this point and at the same time to produce the desired reflux ratio.

Two methods were used to effect a change in reflux ratio:

1. Feed and product rates were held constant while the heat input to the reboiler was changed.
2. Heat input to the reboiler was held constant while the feed, and/or product rates were changed.

In each case the result was a shift in the component distribution, and this necessitated a corresponding period for column readjustment. The bottoms rate was adjusted to maintain a constant liquid level in the reboiler. Continuous feed, product, and bottoms rates were carefully controlled for a period sufficient to produce steady operation as indicated by constant plate temperatures. Samples and data were obtained as during total reflux, with addition of a feed sample, and product flow rate. The bottoms rate was not metered; but it was assumed that the maintenance of constant feed and product rates and a constant liquid level in the reboiler would render the bottoms rate calculable. This assumption required that column holdup be essentially constant, and such a condition should occur under these normal operating procedures.

Samples were analyzed by methods chosen for the system under investigation, and the data were used in calculation of the efficiency of fractionation.

Efficiency, as used in this report, is defined as the ratio of the number of theoretical distillation plates required for a given separation, to the actual number of plates used for that separa-

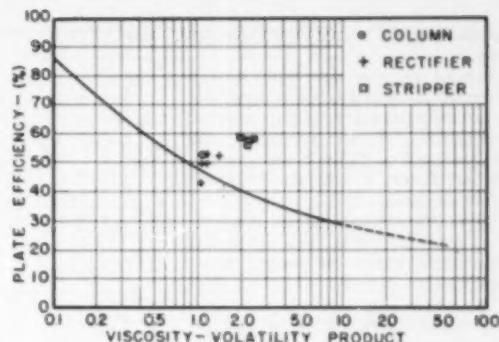


Fig. 4. Plate efficiencies for methanol-water system.

tion. Calculation of the theoretical number of plates was accomplished by the step-by-step procedure of McCabe and Thiele (6) on a plot of the vapor liquid equilibria. Vapor liquid equilibria were plotted on 20 in. \times 20 in. cross-section paper except when accuracy in low composition ranges required the use of a plot on log-log paper (6).

Prior to efficiency calculations on each run a plot was made of the plate sample composition vs. its placement in the column so that abnormalities in distribution, feed mismatch, etc., could be detected. Where feed mismatch was evident, the abnormal data of adjacent plates were not used in calculation of rectifier and stripper efficiencies. Data on runs where feed was excessively mismatched were discarded completely. A check on the method was made by the calculation of two-plate efficiencies throughout the length of the column. Where the two-plate efficiency deviated widely from the average, data were not included in calculation of the over-all column efficiency. This was especially evident in stripping sections of runs on several systems. For ethanol-water, for instance, the stripping action was so rapid that no reliable data could be obtained below the feed plate on the majority of runs. By this method, data from the section of the column over which there was good distribution were selected and used in efficiency determinations.

For correlation of results on all but the system ethanol-water, a pseudo-

molar viscosity was employed, as suggested by Drickamer and Bradford (2). Their method assumed that the viscosities of mixtures could be determined by adding the viscosities of the components at a given temperature in proportion to the mole fraction of each present. Viscosity values for pure components as a function of temperature were obtained from standard references. For the system ethanol-water the actual viscosity data of Surowiec and Furnas were obtained (7) and employed for the correlation. According to the suggested method, viscosity for correlation purposes was taken at an average column temperature. Values used for relative volatility are an average over that portion of the column for which data are presented.

Vapor-liquid equilibria for all systems except pentane-toluene were either smoothed by the method of Carlson and Colburn (1) or taken directly from the literature. For the system pentane-toluene the method of Lewis and Kay (5) was used for calculation of equilibria. Relative volatilities were calculated from equilibrium data, or from fixed points.

Ethanol-Water. The major portion of the work with this system was at total reflux because of difficulties attendant on the procurement of the ethanol sufficient for protracted runs, and with the difficulty of securing constant operating conditions. Stripping below the feed plate was also extremely

TABLE 2 Ethanol - Water Summary Data

| Run No. | Section | Vapor Vel. ft./sec. | Reflux Ratio | x_{B} | x_{D} | Actual Plates | Theoretical Plates | Overall Eff. | Ave. Valued # of 100 | Run No. | | |
|---------|---------|------------------------|--------------|----------------|----------------|---------------|--------------------|--------------|-------------------------|---------|------|---|
| 1 | Rect. | 0.60 | 1 | .013 | .670 | 6 | 3.63 | 45.4 | .598 | 2.6 | 1.66 | 1 |
| 2 | * | 1.04 | 1 | .013 | .670 | 8 | 3.50 | 43.8 | .598 | 3.0 | 1.80 | 2 |
| 3 | * | 0.58 | 1 | .022 | .498 | 6 | 3.90 | 47.6 | .598 | 3.3 | 1.86 | 3 |
| 4 | * | 0.65 | 1 | .008 | .700 | 8 | 3.88 | 48.6 | .598 | 3.5 | 1.80 | 4 |
| 5 | * | 0.71 | 1 | .018 | .759 | 10 | 4.72 | 47.2 | .598 | 1.9 | 1.11 | 5 |
| 6 | * | 1.11 | 1 | .002 | .760 | 10 | 5.25 | 52.5 | .598 | 2.6 | 1.50 | 6 |
| 7 | * | 1.09 | 0.91 | .046 | .675 | 6 | 3.05 | 50.5 | .598 | 2.5 | 1.50 | 7 |

fast and resulted in data which were erratic.

Sample analysis was made with a Westphal balance, which was capable of satisfactory accuracy in the range of investigation. Results for this system are presented in Table 2, and graphically in Figure 3 with the O'Connell reference curve.

Plate efficiencies are in relatively close agreement with each other, and with the O'Connell correlation. Maximum absolute deviation was about 10%.

Methanol-Water. In order that the correlation be checked with a second material in the center of the curve, the common system methanol-water was chosen. One run was made with total reflux, but six acceptable continuous runs were included for this system, using variable reflux ratios and feed plates. Data are presented in Table 3.

Analysis was comparatively easy with the use of the Westphal balance, and no troubles were encountered in the operation except an occasional feed mismatch. The correlation is presented graphically in Figure 4. Rectifier and over-all column efficiencies were in fair agreement with the exception of run number 12. The rectifier on this run produced an efficiency which was in

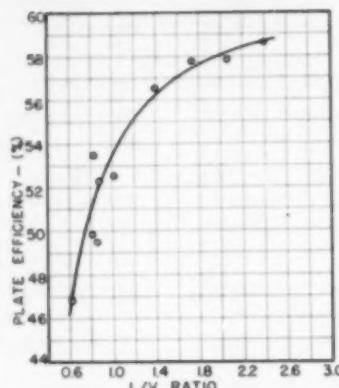


Fig. 3. Effect of liquid-vapor ratio on plate efficiency, methanol-water system

agreement with the other results, but the over-all value was low.

Agreement of the data with the O'Connell correlation is fair, if the stripping efficiencies are disregarded. However, the bunching of these values was disconcerting and led to the belief that other factors might be influencing the values more than was previously believed. Accordingly, a plot was made of the plate efficiencies vs. the L/V ratios

TABLE 3 Methanol - Water Summary Data

| Run No. | Section | Vapor Vol. | \bar{v} | x_1 | x_2 | Actual Plates | Theoretical Plates | Overall Eff. | Ave. Values |
|---------|---------|------------|-----------|-------|-------|---------------|--------------------|--------------|----------------------------|
| | | | | | | | | | μ_a μ_b μ_{ab} |
| 8 | Rect. | 1.07 | 1.00 | 0.075 | 0.925 | 8 | 4.10 | 32.5 | .37 .32 1.18 |
| 9 | Rect. | 0.76 | 0.63 | .206 | .793 | 10 | 4.97 | 42.7 | .36 .31 1.12 |
| 9 | Strip | 2.4 | .006 | .165 | .835 | 8 | 3.52 | 58.6 | .29 6.9 2.00 |
| 9 | Column | | | | | 18 | 9.15 | 50.3 | .35 3.6 1.13 |
| 10 | Rect. | 0.73 | 0.61 | .150 | .850 | 6 | 2.95 | 49.8 | .33 3.1 1.12 |
| 10 | Strip | 1.99 | .009 | .113 | .887 | 2 | 2.93 | 57.8 | .30 7.7 2.32 |
| 10 | Column | | | | | 14 | 5.50 | 47.1 | .34 4.2 1.63 |
| 11 | Rect. | 1.15 | 0.62 | .162 | .837 | 6 | 3.42 | 53.6 | .37 3.4 1.16 |
| 11 | Strip | 2.09 | .006 | .099 | .901 | 2 | 1.53 | 57.0 | .30 8.0 2.40 |
| 11 | Column | | | | | 12 | 5.01 | 48.8 | .35 4.5 1.58 |
| 12 | Rect. | 1.16 | 0.67 | .190 | .809 | 4 | 2.69 | 57.2 | .30 3.0 1.60 |
| 12 | Column | | | | | 12 | 6.17 | 34.6 | .35 5.2 1.82 |
| 13 | Rect. | 0.61 | 0.69 | .143 | .857 | 6 | 2.77 | 47.4 | .36 3.5 1.26 |
| 13 | Strip | 1.40 | .005 | .143 | .857 | 4 | 2.76 | 56.3 | .30 7.6 2.38 |
| 13 | Column | | | | | 10 | 5.23 | 52.3 | .39 4.2 1.62 |

TABLE 4 Benzene - Toluene Summary Data

| Run No. | Section | Vapor Vol. | \bar{v} | x_1 | x_2 | Actual Plates | Theoretical Plates | Overall Eff. | Ave. Values |
|---------|---------|------------|-----------|-------|-------|---------------|--------------------|--------------|----------------------------|
| | | | | | | | | | μ_a μ_b μ_{ab} |
| 14 | Column | 0.50 | 1.00 | 0.005 | 0.995 | 10 | 10.5 | 98 | .29 2.66 0.725 |
| 15 | * | .26 | 0.75 | .02 | .978 | 10 | 12.9 | 72 | .29 2.66 .725 |
| 16 | * | .41 | 1.00 | .005 | .995 | 10 | 10.5 | 98 | .29 2.66 .725 |
| 17 | * | .70 | 0.78 | .07 | .92 | 10 | 10.6 | 98 | .29 2.66 .725 |
| 18 | * | .49 | 1.00 | .07 | .92 | 14 | 7.6 | 96 | .28 2.69 .695 |
| 19 | * | .60 | 0.63 | .07 | .92 | 14 | 7.0 | 90 | .29 2.69 .695 |
| 20 | * | .56 | 1.00 | .12 | .88 | 14 | 6.5 | 46 | .29 2.69 .695 |
| 21 | * | .66 | 0.86 | .11 | .88 | 14 | 7.0 | 50 | .29 2.66 .725 |

which were used, and it is presented in Figure 5. The widely scattered points here begin to form a pattern which is incomplete in this system, but which was shown to be somewhat followed by subsequent data. It should be noted that the viscosity-relative volatility product was not constant for all these runs, and exact agreement would be unexpected.

Benzene-Toluene. This system has been widely studied, and was included as a comparison group as well as a satisfactory pair of substances for one section of the curve. Considerable trouble was encountered in the experimental procedure for analysis, and the final methods involved freezing-point determinations for the benzene-rich materials, and vapor-pressure analyses for the toluene-rich fractions. This latter was by the procedure of Natelson and Zucker (7). Accuracies obtained by these methods were within 1% by direct experiment, and were considered satisfactory for the work. Results were measured in the same manner as the other systems, but over-all column efficiencies were the only values calculated because of the inability to obtain accurate analyses at the intermediate compositions.

A compilation of the results is given in Table 4 and in Figure 6. There is good agreement with the correlation, and with values of other investigators with the exception of run number 15. This run has been examined carefully to discover the reason for the abnormal results, but there were no experimental conditions which would warrant a discarding of the values. This one value, however, should be considered as unrepresentative.

Benzene-Carbon Tetrachloride. This system offered three points of difference, and was chosen for these reasons:

1. Low value of relative volatility, placing μ_a product in low end of curve
2. System where material of higher density was being driven up column
3. System combining a typical cyclic with a saturated and chlorinated single carbon compound

Density methods by the Westphal balance method were simple and accurate for the analyses of these mixtures, and runs of all types were made with this system. The initial runs showed a considerable spread in the data, so additional runs were made as checks. The spread continued, but the average values were acceptable. A correlation was attempted, as with the methanol-water system, with L/V as the parameter, but the trend was the reverse of the prev-

ious system, and rather scattered in actual points. This correlation is demonstrated in Figure 7. The decrease of vapor velocities actually contributed more to narrowing the spread than any other factor.

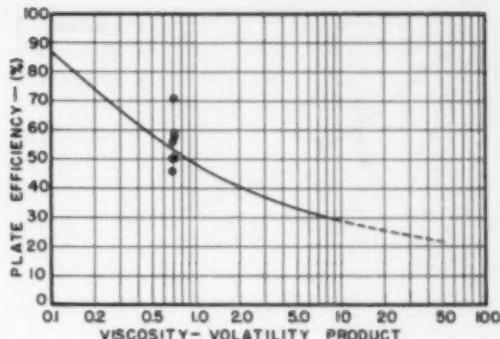
Summary data for this system are presented in Table 5 and Figure 8.

Acetaldehyde-Water. This system was chosen for its high relative volatility, and the opportunity to combine water and an aldehyde mixture. Considerable difficulty was experienced in obtaining a sufficient distribution of acetaldehyde in the column, but a series of runs was completed in which total reflux and continuous operation were represented, as well as both rectification and stripping sections. The Westphal balance was again used for analysis, although the plate temperatures had to be checked also to prevent ambiguity caused by the presence of a density maximum in the curve. Data for the runs are found in Table 6 and correlated in Figure 9.

With the exception of the stripper efficiencies, results are in relatively close agreement both with each other and with the O'Connell curve, and if the previous L/V factor has real applicability, this deviation is similar to what would be predicted.

Acetone-Water. The acetone-water system was suggested for examination, although it was expected that the viscosity-relative volatility product would be close to that of the first two systems, because of the ketone-water system type, and its normal differences from the alcohols. The low boiling point of the acetone and the high volatility in the region under investigation presented considerable difficulty in matching the feed to the column distribution, and in holding a reasonably wide distribution of acetone on the plates. This was particularly difficult in the early central feed runs, but was evaded in later runs with almost the entire column being used as a stripper, and a high value of

Fig. 6. Plate efficiencies for benzene-toluene system.



L/V for the operation. The change was obtained by a decrease in the amount of vapor rising in the column rather than by an increase in the liquid downstream.

and there was no evidence of flooding.

The Westphal balance was used for a portion of the analyses, but where the quantity of acetone was very low, it was

TABLE 5 Benzene - Carbon Tetrachloride Summary Data

| Run No. | Section | Vapor Vel. | L/V | x_{B} | x_{N} | Actual Plates | Theoretical Plates | Overall Eff. | Ave. Values |
|---------|---------|------------|-------|---------|---------|---------------|--------------------|--------------|----------------|
| | | | | | | | | | % |
| 22 | Column | 0.74 | 1.00 | 0.62 | 0.63 | 18 | 9.5 | 53 | 0.39 1.10 0.63 |
| 23 | Column | 1.05 | | .38 | .54 | 18 | 13.6 | 76 | .37 1.12 0.60 |
| 23 | Rect. | 1.05 | 0.76 | .48 | .54 | 6 | 4.4 | 73 | .38 1.11 0.62 |
| 23 | Strip | | | .38 | .44 | 8 | 4.0 | 50 | .36 1.13 0.61 |
| 24 | Column | 0.98 | | .33 | .52 | 18 | 11.5 | 60 | .36 1.13 0.60 |
| 24 | Rect. | 0.98 | 0.84 | .63 | .52 | 8 | 5.2 | 65 | .37 1.12 0.62 |
| 24 | Strip | | | .33 | .62 | 8 | 5.0 | 68 | .36 1.16 0.39 |
| 25 | Column | 0.82 | 1.00 | .32 | .56 | 18 | 8.2 | 66 | .36 1.13 0.40 |
| 26 | Column | 0.96 | 1.00 | .43 | .66 | 18 | 10.1 | 56 | .39 1.10 0.63 |
| 27 | Column | 0.83 | 1.00 | .39 | .64 | 18 | 10.6 | 59 | .39 1.10 0.63 |
| 28 | Column | 1.00 | | .38 | .58 | 18 | 10.8 | 60 | .38 1.11 0.62 |
| 28 | Rect. | 1.00 | 0.86 | .49 | .58 | 6 | 5.5 | 59 | .39 1.10 0.63 |
| 28 | Strip | | | .39 | .68 | 8 | 4.0 | 51 | .36 1.13 0.61 |
| 29 | Column | 1.02 | | .31 | .53 | 18 | 9.4 | 52 | .36 1.13 0.61 |
| 29 | Rect. | 1.02 | 0.93 | .69 | .57 | 4 | 2.6 | 66 | .39 1.10 0.62 |
| 29 | Strip | | | .31 | .67 | 12 | 5.7 | 48 | .35 1.16 0.60 |
| 30 | Column | 1.02 | | .30 | .56 | 18 | 9.0 | 50 | .36 1.13 0.61 |
| 30 | Rect. | 1.02 | 0.92 | .36 | .56 | 14 | 7.1 | 51 | .37 1.13 0.62 |
| 30 | Strip | | | .30 | .56 | 6 | 1.9 | 47 | .36 1.17 0.60 |
| 31 | Column | 0.93 | 1.00 | .48 | .68 | 18 | 9.8 | 55 | .40 1.08 0.63 |
| 32 | Column | 1.02 | | .39 | .56 | 18 | 13.1 | 73 | .38 1.12 0.63 |
| 32 | Rect. | 1.02 | 0.85 | .68 | .56 | 6 | 4.7 | 76 | .38 1.11 0.62 |
| 32 | Strip | | | .38 | .62 | 4 | 2.6 | 65 | .36 1.14 0.61 |
| 33 | Column | .99 | | .32 | .52 | 18 | 10.1 | 56 | .36 1.13 0.61 |
| 33 | Rect. | .99 | 0.86 | .42 | .52 | 8 | 5.2 | 66 | .37 1.12 0.61 |
| 33 | Strip | | | .32 | .60 | 8 | 4.0 | 50 | .35 1.15 0.60 |
| 34 | Column | 1.09 | | .28 | .52 | 18 | 9.0 | 50 | .36 1.14 0.61 |
| 34 | Rect. | 1.09 | 0.93 | .62 | .52 | 8 | 4.3 | 54 | .37 1.12 0.61 |
| 34 | Strip | | | .28 | .58 | 8 | 3.7 | 47 | .34 1.15 0.39 |
| 35 | Column | 0.74 | 1.00 | .42 | .66 | 18 | 9.9 | 55 | .39 1.11 0.63 |
| 36 | Column | 0.77 | | 0.62 | 0.58 | 18 | 12.0 | 67 | 0.38 1.11 0.62 |
| 36 | Rect. | 0.77 | 0.86 | .69 | .58 | 8 | 5.5 | 60 | .39 1.10 0.63 |
| 36 | Strip | | | 0.62 | .66 | 4 | 2.7 | 67 | .36 1.13 0.62 |
| 37 | Column | 0.79 | | .40 | .58 | 18 | 12.1 | 66 | .38 1.11 0.63 |
| 37 | Rect. | 0.79 | 0.87 | .69 | .58 | 8 | 5.9 | 73 | .39 1.10 0.63 |
| 37 | Strip | | | .40 | .66 | 6 | 3.8 | 63 | .36 1.13 0.62 |

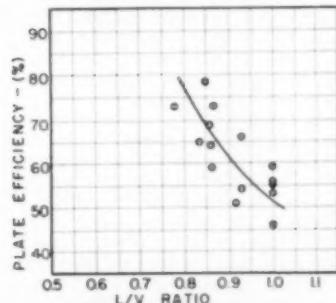


Fig. 7. Effect of liquid-vapor ratio on plate efficiency, benzene-carbon tetrachloride system.

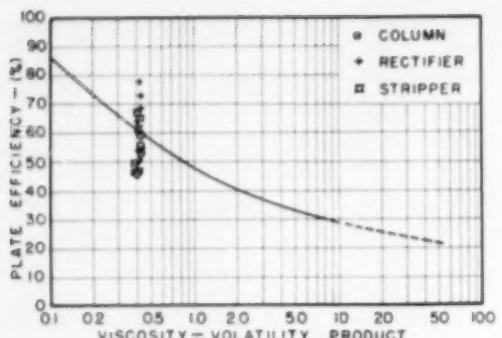


Fig. 8. Plate efficiencies for benzene-carbon tetrachloride system.

found necessary to employ an A.S.T.M. pycnometer with side arm and thermometer. The accuracy was thereby increased to satisfactory levels. Over-all and rectification efficiencies again appear to give fair correlation, as shown

in Table 7 and Figure 10, but again the stripper efficiencies are relatively high. One over-all figure is also somewhat high, but it is noted that the rectification figure for this run is in line, and that a highly efficient but short stripper sec-

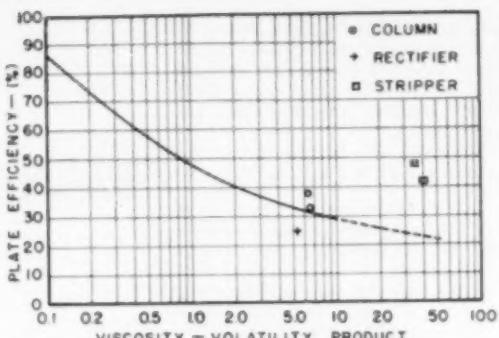


Fig. 9. Plate efficiencies for acetaldehyde-water system.

tion would account for the difference. Stripping efficiencies again deviate considerably from the O'Connell curve, but when plotted against the L/V ratio (Fig. 11) correlation is again obtained, with the exception of one run. It is interesting that the extrapolation of the L/V correlation produces a stripping efficiency of between 10 and 20% at an L/V value of about one; this value would not be too far from the O'Connell prediction.

Methyl Ethyl Ketone-Water. This system is of a high viscosity-volatility product, and is a characteristic partially miscible system. Accordingly all runs were made with continuous feed to the top of the column and the entire column operated under stripping conditions. This operation resulted in column sensitivity and many runs were discarded because of fluctuations caused by slight steam variation. Distribution was also difficult to obtain, and high liquid feed rates were necessary, limiting the time of operation to approximately one hour per run. It was considered that this was satisfactory, although it added to the difficulty of operation. The product separated into two layers, and it was necessary to estimate the overhead rate volumetrically in order to obtain material balances for the runs. The analysis necessitated accurate methods, which were furnished by freezing-point determinations on the samples. Calculation of theoretical plates required log-log plots of the equilibrium curve, which was calculated by a method (7) for partially miscible systems.

Data presented in Table 8 and Figure 12 indicate that there is no correlation possible according to the O'Connell plot, but when the data are plotted vs. the L/V ratio, a smooth curve again is obtained. The extrapolated plate efficiency at a value of $L/V = 1$ comes between 10% and 20%, which more closely approaches the presupposed curve (Fig. 13).

TABLE 6 Acetaldehyde - Water Summary Data

| Run No. | Section | Vapor Rate | $\frac{L}{V}$ | x_0 | x_0 | Actual Plates | Theoretical Plates | Overall Eff. | Ave. Values | | |
|---------|---------|------------|---------------|-------|-------|---------------|--------------------|--------------|-------------|------------|--------------|
| | | | | | | | | | Δ | ΔL | Δx_0 |
| 36 | Strip. | | | .005 | .305 | 4 | 1.30 | 48 | .130 | .97 | .39 |
| 37 | Column | 0.48 | 1.00 | .006 | .98 | 6 | 2.63 | 33 | .30 | 1.9 | 6.6 |
| 38 | Column | 0.43 | | .006 | .96 | 8 | 2.87 | 35 | .46 | 2.5 | 26 |
| 39 | Rect. | 0.43 | 0.60 | .475 | .76 | 4 | 1.00 | 25 | .36 | 1.9 | 5.3 |
| 40 | Strip. | | | .006 | .475 | 4 | 1.67 | 68 | .50 | .97 | .40 |
| 41 | Column | 0.46 | 1.00 | .521 | .985 | 4 | 1.50 | 38 | .37 | 18.5 | 6.4 |

TABLE 7 Acetone - Water Summary Data

| Run No. | Section | Vapor Rate | $\frac{L}{V}$ | x_0 | x_0 | Actual Plates | Theoretical Plates | Overall Eff. | Ave. Values | | |
|---------|---------|------------|---------------|-------|-------|---------------|--------------------|--------------|-------------|------------|--------------|
| | | | | | | | | | Δ | ΔL | Δx_0 |
| 42 | Column | 0.86 | 1.00 | .005 | .975 | 8 | 4.52 | 57 | .033 | 4.7 | 1.56 |
| 43 | Rect. | 0.79 | 0.60 | .375 | .92 | 6 | 4.50 | 58 | .10 | 2.7 | 0.81 |
| 44 | Column | | | .005 | .92 | 10 | 6.00 | 68 | .10 | 3.8 | 1.22 |
| 45 | Rect. | 1.00 | 0.80 | .875 | .97 | 6 | 3.88 | 58 | .29 | 2.0 | 0.56 |
| 46 | Strip. | 0.9 | 0.4 | .0004 | .058 | 6 | 3.8 | 57 | .28 | 28.5 | 8.0 |
| 47 | Strip. | 0.50 | 0.9 | .0001 | .056 | 10 | 7.0 | 70 | .10 | 28.5 | 8.7 |
| 48 | Strip. | 0.37 | 0.7 | .0002 | .0518 | 4 | 1.95 | 48 | .025 | 28.5 | 8.7 |
| 49 | Strip. | 0.72 | 1.57 | .0001 | .0322 | 6 | 2.87 | 56 | .205 | 23.0 | 7.20 |
| 50 | Strip. | 0.39 | 10.07 | .0114 | .0340 | 2 | 1.64 | 75 | .33 | 26.15 | 8.63 |

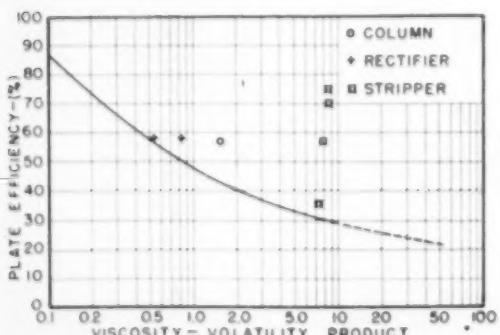


Fig. 10. Plate efficiencies for acetone-water system.

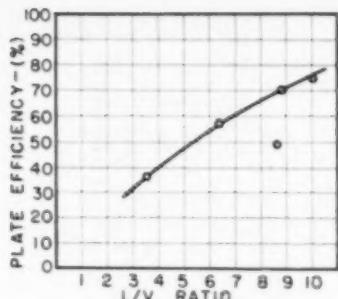


Fig. 11. Effect of liquid-vapor ratio on stripping efficiencies of acetone-water system.

Pentane-Toluene. The system pentane-toluene was chosen to fit the medium high ranges of viscosity-volatility product with the combination of an aromatic and an aliphatic hydrocarbon. This system was sensitive also to steam variation and mismatch of feed plate, but runs were obtained at total reflux and with both stripping and rectification at continuous feed. Analysis was with the Westphal balance, and the equilibrium curve was calculated by the method of Lewis and Kay (5).

As shown in Table 9 and Figure 14, good agreement was shown to the correlation except in the case of three stripper sections. Data are not sufficiently spread to evaluate accurately this system on the L/V plot, but the data are bunched close enough to substantiate use of a curve similar to those previously drawn. It is noted that the stripping efficiency value as shown in Figure 15, approximates the O'Connell curve only at the low L/V ratios.

Comment

Data from all systems have been assembled in Figure 16, where the nature of the point (column, rectifier, or stripper) has been used as the criterion for designation. If both rectifying and stripping sections are plotted for a single run, the over-all efficiency point has been deleted in order to present the data more accurately. Cursory examination of the results would lead to the

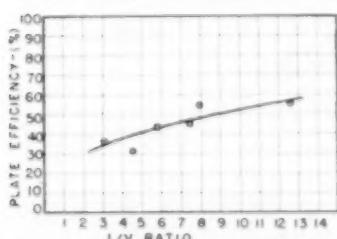


Fig. 13. Effect of liquid-vapor ratio on stripping efficiencies of methyl ethyl ketone-water system.

Fig. 12. Plate efficiencies for methyl ethyl ketone - water system.

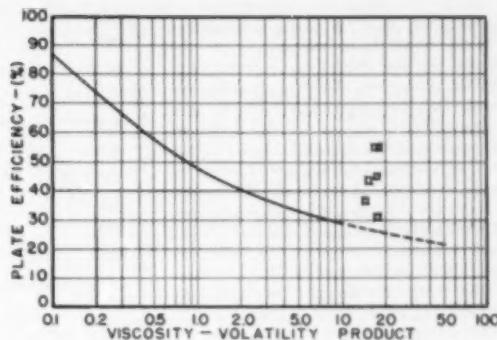


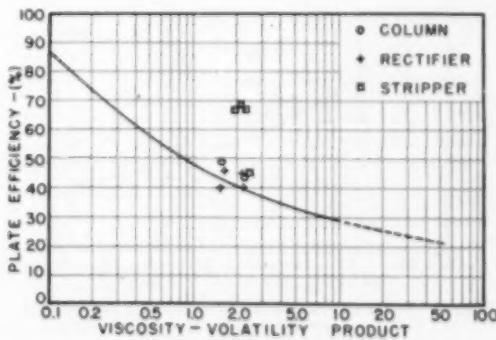
TABLE 8 Methyl Ethyl Ketone-Water Summary Data

| Run No. | Section | Vapor Vol. | $\frac{L}{V}$ | x_{R} | x_{B} | Actual Plates | Theoretical Plates | Overall Eff. | Ave. Values |
|---------|---------|------------|---------------|----------------|----------------|---------------|--------------------|--------------|----------------|
| 51 | Strip. | 0.71 | 3.11 | .0001 | .0079 | 4 | 1.65 | 36.2 | 0.89 50.0 14.6 |
| 52 | Strip. | 0.29 | 12.5 | .0001 | .0288 | 8 | 5.6 | 57.0 | 0.38 54.6 17.8 |
| 53 | Strip. | 0.71 | 4.52 | .0001 | .0064 | 4 | 1.45 | 36.8 | 0.88 54.0 17.7 |
| 54 | Strip. | 0.66 | 7.47 | .0001 | .0186 | 6 | 2.6 | 45.0 | 0.32 53.8 17.3 |
| 55 | Strip. | 0.66 | 7.95 | .0001 | .0078 | 4 | 2.63 | 54.3 | 0.31 54.3 16.9 |
| 56 | Strip. | 0.20 | 5.8 | .0003 | .0512 | 6 | 2.87 | 43.3 | 0.31 48.8 15.1 |

TABLE 9 Pentane - Toluene Summary Data

| Run No. | Section | Vapor Vol. | $\frac{L}{V}$ | x_{R} | x_{B} | Actual Plates | Theoretical Plates | Overall Eff. | Ave. Values |
|---------|---------|------------|---------------|----------------|----------------|---------------|--------------------|---------------|----------------|
| 57 | Column | 0.24 | 1.00 | .042 | .972 | 6 | 3.5 | 43.8 | 0.36 8.65 2.85 |
| 58 | Column | 0.03 | 1.50 | .262 | .983 | 6 | 2.93 | 49.0 | 0.30 7.8 1.56 |
| 59 | Column | 0.14 | - | .07 | .998 | 16 | 8.6 | 52.5 | 0.37 6.75 2.36 |
| 59 | Rect. | 0.46 | .259 | .986 | - | 10 | 4.0 | 40.0 | 0.22 6.9 1.52 |
| 59 | Strip. | 2.38 | .007 | .099 | - | 6 | 4.0 | 66.6 | 0.77 7.75 1.98 |
| 60 | Column | 0.30 | - | .0120 | .971 | 10 | 5.6 | 56.0 | 0.38 8.6 2.65 |
| 60 | Rect. | 0.596 | .301 | .971 | - | 9 | 2.7 | 45.0 | 0.26 8.4 2.18 |
| 60 | Strip. | 1.73 | .0140 | .001 | - | 4 | 2.75 | 69.0 | 0.38 7.45 2.12 |
| 61 | Column | 0.07 | - | .119 | .999 | 34 | 5.6 | 35.7 | 0.29 8.6 2.36 |
| 61 | Rect. | 0.66 | .381 | .995 | - | 3.7 | 46.2 | 0.22 7.3 1.64 | |
| 61 | Strip. | 1.52 | .119 | .902 | - | 1.9 | 45.0 | 0.39 8.4 2.68 | |
| 62 | Column | 0.12 | - | .0065 | .997 | 16 | 7.7 | 42.7 | 0.27 8.75 2.36 |
| 62 | Rect. | 0.963 | .772 | .997 | - | 3.2 | 40.0 | 0.31 7.0 2.16 | |
| 62 | Strip. | 2.25 | .0065 | .294 | - | 4 | 2.7 | 67.5 | 0.31 7.5 2.39 |

Fig. 14. Plate efficiencies for Pentane-Toluene system.



conclusion that a better correlation would result from the raising of the curve in the high viscosity-volatility range. However, closer observation reveals that the major reason for the first impression is caused by the series of stripper points, adequately shown by the subsequent plots of Figure 17, rectifier and total reflux column efficiencies. This curve, deleting the stripper values, shows adequate support for the O'Connell correlation. However, the auxiliary plots with correlations on an L/V basis indicate that the degree of variance may be due in part to some operating condition associated with this parameter.

Notation

Actual Number of Plates. Number of plates in section considered over which data were of sufficient precision to use in calculations—not necessarily the number of plates between feed and product or between feed and waste. Number of plates which produced enrichment from x_m to x_n .

Average Column Temperature. Average temperature of liquid on plates being considered.

Liquid-Vapor Ratio (L/V). Ratio of moles of liquid descending to moles of vapor rising at any point in column.

Over-all Efficiency. The ratio of the number of theoretical plates to the number of actual plates. Over-all rectifier efficiency includes only the section of the column above the feed plate; over-all stripper efficiency, section below feed plate, and over-all column efficiency, entire section including feed plate.

Pseudo-Molal Viscosity (μ). A pseudo-viscosity based on a direct composition relationship.

Operating Ratio. The liquid-vapor ratio in rectifying sections.

Louisville, Institute of Industrial Research, made possible the obtainment and publication of these data.

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Discussion

J. H. Koffolt (Ohio State University, Columbus, Ohio): Offhand and on the basis of work we have done on a three-plate, 7-in. diameter column (2), we are not surprised at the scattering of his points. We have found (2) that a practical and a good correlation of results was obtained by plotting efficiencies vs. m_0 , the average slope of the vapor-liquid equilibria curve with V/L , the vapor-liquid ratio as a parameter. This correlation was suggested by the fundamental equation derived by Colburn (1). It will be interesting to plot Dr. Williams' data along these same lines to determine whether the systems he has used and his particular column will give the same correlation.

Along the same lines we found that at constant m_0 , the efficiencies increased with L/V , the liquid-vapor ratio. It is noted that most of Dr. Wil-

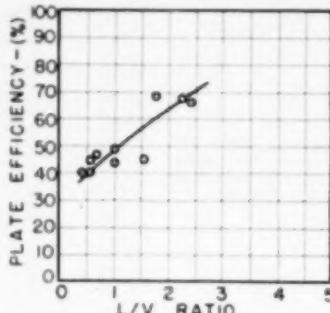


Fig. 15. Effect of liquid-vapor ratio on plate efficiency of pentane-toluene system.

Relative Volatility (α). Ratio of mole fractions of more volatile component in vapor to less volatile component in vapor divided by the ratio of the more volatile component in liquid to the less volatile component in liquid.

Theoretical Number of Plates. Number of plates necessary to produce a given separation when ideal interchange exists between the phases, calculated by the method of McCabe and Thiele or a modification thereof.

Vapor Velocity. Superficial velocity of the vapor rising in column, based on diameter D of column and expressed in feet per second.

x_m and x_n . Respectively the composition of the liquid on the bottom plate, and the plate next above section of column under consideration.

Reflux Ratio. Molal ratio of reflux to distillate at top of column.

Acknowledgment

The authors wish to acknowledge the assistance and cooperation of The Ethyl Corp., who through the University of

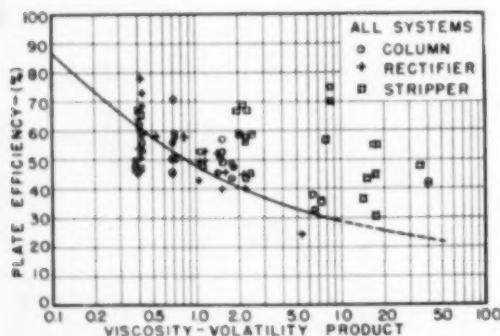


Fig. 16. Effect of viscosity and relative volatility product on plate efficiency. Complete data for all systems.

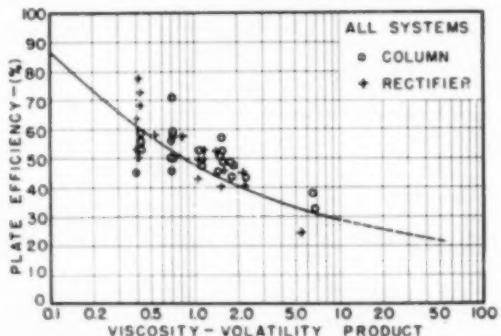


Fig. 17. Effect of viscosity-volatility product on plate efficiencies, for rectifiers and total reflux columns.

liams' data also showed the same trend. Colburn's equation indicates this.

- Colburn, A. P., *Trans. Am. Inst. Chem. Engrs.*, **35**, 311, 590 (1939).
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H. E. O'Connell (Ethyl Corp., Baton Rouge, La.): Since we were responsible for the original correlation (*3*), we wish to point out again more fully the implications and limitations of the correlation.

The correlation was presented as a tool to permit the design engineer to estimate the plate efficiency of fractionating towers. The correlation is semiempirical because it is based on the theoretical plate concept which in itself is a semiempirical relationship.

The theoretical plate concept assumes that the vapor and liquid entering the plate are completely mixed and the resulting leaving vapor and liquid are in equilibrium. As is well known, this is not the case because:

a. There is a concentration gradient of the liquid and a concentration gradient of the vapor across the plate, and thus the liquid leaving the plate is, in a lot of cases, far from equilibrium with the vapor leaving the plate. Actually, on a bubble-cap plate, there is a series of successive contacts on each plate.

b. There is inadequate contact of liquid and vapor at each cap. Actually, if true equilibrium were reached at each cap, over-all plate efficiencies more than 100% would be obtained because as shown by (a) each plate is a number of successive contacts.

The correct solution for fractionating towers involves calculating the differential change in composition of the liquid throughout the path it follows in the tower. Even if the effect of the mixing of the liquid on the plate could be predicted and the diffusion coefficients could be calculated, such a procedure would be a lengthy and difficult job. Therefore, at least for the present, we must use the theoretical plate concept and with it a semiempirical plate efficiency relationship.

2. Although the correlation was presented as a semiempirical relationship, there is some theoretical significance in the variables. As shown by Chilton and Colburn (*1*), mass trans-

TABLE 10. SAMPLE ORIGINAL DATA FOR PLATE EFFICIENCY INVESTIGATION

| ROW NO. | S | | 13 | | 19 | | 33 | |
|------------|---|-------------------|--|-----|---|-----|--|----|
| | A | B | A | B | A | B | A | B |
| COMPONENT | $\text{C}_2\text{H}_5\text{OH} \sim \text{H}_2\text{O}$ | | $\text{CH}_3\text{COCH}_3 \sim \text{H}_2\text{O}$ | | $\text{C}_2\text{H}_5 \sim \text{C}_2\text{H}_5\text{CO}_2$ | | $\text{C}_2\text{H}_5 \sim \text{C}_2\text{H}_5\text{O}$ | |
| SYSTEM | | | | | | | | |
| OPERATION | Total reflux | Continuous Column | | | Continuous Column | | Continuous Column | |
| FEED PLATE | | | | | | | | |
| REFLUX | 1200/hr \pm 35°C | 720/hr \pm 30°C | | | 1600/hr \pm 35°C | | 3600/hr \pm 35°C | |
| PRODUCT | | | 136/hr \pm 30°C | | 336/hr \pm 35°C | | 648/hr \pm 35°C | |
| FEED | | | 300/hr \pm 65°C | | 1000/hr \pm 65°C | | 260/hr \pm 55°C | |
| | SA | %C | SA | %C | SA | %C | SA | %C |
| 9 | 77.4 | 78 | 91.6 | 68 | 99 | 80 | 56 | 77 |
| 1 | 75.9 | 78 | 87.5 | 68 | 99 | 80 | 54.5 | 77 |
| 2 | 71.7 | 78 | 89.5 | 70 | 99 | 82 | 68.5 | 77 |
| 3 | 67.5 | 78.5 | 43.4 | 76 | 96 | 82 | 46.5 | 77 |
| 7 | 58.0 | 79.9 | 14.3 | 89 | 94 | 82 | 44 | 78 |
| 9 | 31.5 | 83 | 1.5 | 97 | 88 | 83 | 42 | 78 |
| 11 | 1.5 | 96 | 0.5 | 98 | 65 | 85 | 40.5 | 78 |
| 13 | 0.3 | 99.5 | 0.6 | 98 | 47 | 90 | 39 | 79 |
| 15 | 0.4 | 100 | 0.4 | 98 | 39 | 94 | 37 | 79 |
| 27 | 0.2 | 100 | 0.6 | 98 | 28 | 97 | 38 | 79 |
| 39 | 0.3 | 100 | 0.4 | 100 | 20 | 102 | 32.5 | 79 |
| Bottoms | 0.2 | — | 0.6 | — | 9 | — | 32 | — |
| Feed | — | — | 25.3 | — | 32 | — | 40.5 | — |

TABLE 10. SAMPLE ORIGINAL DATA FOR PLATE EFFICIENCY INVESTIGATION (CONT'D)

| ROW NO. | 40 | | 46 | | 94 | | 61 | |
|------------|---|-----|--|-----|--|------|---|------|
| | A | B | A | B | A | B | A | B |
| COMPONENT | $\text{CH}_3\text{CHO} \sim \text{H}_2\text{O}$ | | $\text{CH}_3\text{COCH}_3 \sim \text{H}_2\text{O}$ | | $\text{CH}_3\text{OC}_2\text{H}_5 \sim \text{H}_2\text{O}$ | | $\text{C}_2\text{H}_5\text{O}_2 \sim \text{C}_2\text{H}_5\text{CH}_3$ | |
| SYSTEM | | | | | | | | |
| OPERATION | Continuous Column | | Continuous Column | | Continuous Stripping | | Continuous Column | |
| FEED PLATE | 9 | — | 1 | — | 3 | — | 13 | — |
| REFLUX | 630/hr \pm 20°C | | | | | | 360/hr | |
| PRODUCT | 420/hr \pm 20°C | | 600/hr \pm 20°C | | 400/hr | | 90/hr | |
| FEED | 1600/hr \pm 20°C | | 2600/hr \pm 65°C | | 3700/hr \pm 70°C | | 1100/hr \pm 25°C | |
| | SA | %C | SA | %C | SA | %C | SA | %C |
| 9 | 91.5 | 20 | 61.8 | 99 | 98 | 78 | 100 | 100 |
| 1 | 96.2 | 20 | 5.45 | 99 | 75 | 99.9 | 99.9 | 99.9 |
| 3 | 77.5 | 23 | 0.80 | 94 | 1.89 | 78 | 99.6 | 98 |
| 5 | 36 | 21 | 0.093 | 99 | 1.86 | 79 | 91.5 | 90 |
| 7 | 84.3 | 22 | 0.022 | 100 | 0.031 | 79 | 98.6 | 98 |
| 9 | 43.5 | 26 | 0.007 | 100 | 0.10 | 84 | 95.0 | 96 |
| 11 | 34.6 | 33 | — | 100 | 0.01 | 95 | 88.4 | 89 |
| 13 | 0.6 | 75 | — | 100 | — | 100 | 35.1 | 57 |
| 15 | 0.8 | 100 | — | 100 | — | 100 | 97.9 | 94 |
| 17 | 0 | 100 | — | 100 | — | 100 | 30.2 | 86 |
| 19 | 1.2 | 100 | — | 100 | — | 100 | 11.9 | 81 |
| Bottoms | 29.2 | — | — | — | 1.56 | — | 2.4 | — |
| Feed | — | — | 9.7 | — | 1.56 | — | 36.7 | — |

* See Note, page 7.

fer of vapors and liquids is a function of viscosity. The effect of relative volatility possible shows because the relative volatility is approximately proportional to the slope of the equilibrium curve. As shown by Gerster, Koffolt, and Withrow (*2*), the overall plate efficiency is a function of the slope of the equilibrium curve.

3. Limitations of the correlation evidently were not adequately covered in the original paper (*3*). The correlation holds for only:

a. Column designs similar to columns on which the correlation was based. Actually, there is quite a latitude in tray design.

b. Columns where the liquid path is less than 5 ft. For longer liquid paths, efficiencies given in the correlation are low. For liquid paths of 10 to 15 ft., there are indications that efficien-

cies given by the correlation should be increased by 25 to 35%.

c. Columns operating near the minimum reflux. As shown by Dr. Williams and Dr. Souders and as mentioned by others in the literature (for example, Gerster, Koffolt and Withrow (*2*)), high reflux ratios gave efficiencies above those predicted by the correlation.

The effect of the high reflux ratios is probably indirect. In examining data reported by Dr. Williams, it was noticed that the high reflux ratios resulted from an increase in liquid rates since the vapor rate was kept constant. Calculations were made which showed that these high liquid rates increased the submergence appreciably percentagewise. It is possible that this increased submergence caused the increase in efficiency at high reflux ratios.

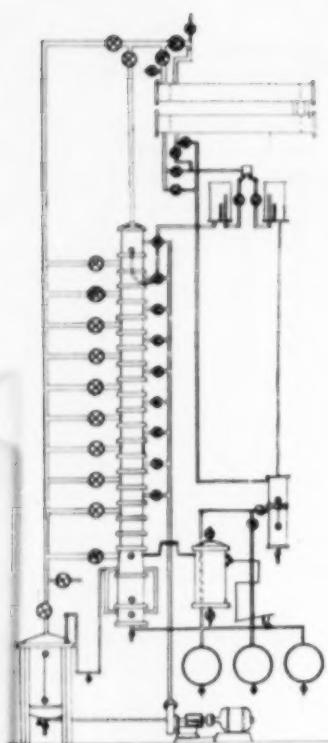


Fig. 18. Experimental distillation column.

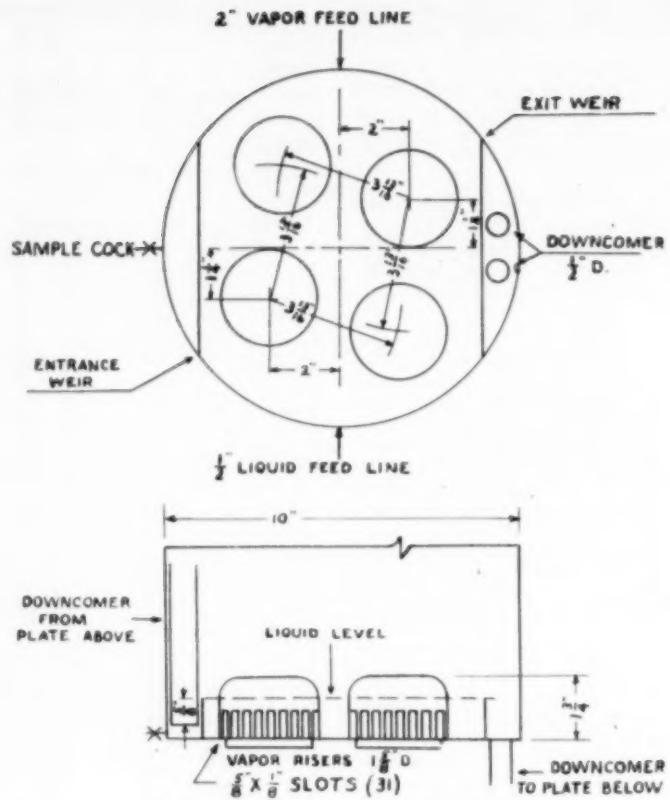


Fig. 19. Details of plate Construction.

d. Columns designed by accurate methods of calculating theoretical plates and with reliable vapor-liquid equilibrium data. The importance of reliable vapor-liquid equilibrium data can be demonstrated by experiments on the benzene-carbon tetrachloride system reported by Dr. Williams. For this system, efficiencies varied from 45 to 78%. However, a 5% error in the vapor-liquid equilibrium data could account for this spread.

Physical properties in the correlation should be measured at the average composition, temperature and pressure over the section of the tower concerned. Actually, in many cases it is possible to use the feed as representing the average liquid composition in the tower and the average of the top and bottom temperature and pressure. Viscosities are actual viscosities, although in many cases the molal average viscosity will approach the true viscosity.

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E. Gelus (Shell Oil Co., Houston, Tex.): Professor Williams presented data which show that over-all Murphree plate efficiencies under stripping operation are higher than under rectifying operation. This same trend was noted by Dr. Sonders and co-workers in their critical study of the performance of a refinery tower. Likewise we have observed a similar trend in some eighteen out of nineteen performance studies on various refinery towers. In the course of these studies an observation was made which may suggest an approach for explaining this trend. A window was installed in one of refinery towers under study and visual observations of tray actions were made under various conditions of operation. One series of

runs was made while maintaining the mass vapor rate constant and varying the liquid rate corresponding to a range of vapor-liquid ratios of 0.6-2.0. It was observed that the spray level over the trays decreased with decreasing liquid load, approaching a constant value above vapor-liquid ratios greater than unity. Coincident with the decrease in spray level, the calculated Murphree point efficiency decreased from a value of about 80% and approached a constant value of about 40%. This suggests, of course, that the rate of mass transfer may be higher in the dispersed spray zone than in the froth layer immediately above the bubble-cap slots. It is suggested that a fundamental investigation of the factors controlling mass transfer in vapor continuous as well as liquid continuous systems would be of considerable theoretical as well as practical interest.

(Presented at Forty-first Annual Meeting, New York, N. Y.)

PERFORMANCE OF DRIP-POINT GRID TOWER PACKINGS

IV. ADDITIONAL GAS-FILM MASS-TRANSFER COEFFICIENTS

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Additional measurements of the rate of absorption of ammonia in water have been made using the apparatus and No. 6295 Drip-Point Grid packing described in the preceding papers in this series (6-7). Tests were made at six constant liquor rates ranging from 1,900 to 15,000 lb./(sq.ft.)(hr.), using several gas rates in the range 100 to 1100 lb./(sq.ft.)(hr.) at each of the liquor rates. While over-all coefficients were found to be functions of liquid rate, the gas-film coefficients were not affected by liquid flow. The general equation found for the gas-film coefficients was

$$k_{G}a = 0.0774G^{0.839}$$

The experimental values are slightly more than twice those predicted by the Sherwood-Gilliland equation for wetted wall columns; there is strong evidence that entrance turbulence accounts for the deviation. This is probably the most extensive set of data available for a single packing and a single solute.

In the design of absorption equipment, it is necessary that the engineer be able to predict the performance of each type of equipment being considered. It is hoped that eventually performance can be predicted for any combination of solvent, solute, inert gas, apparatus and flow rates from test data involving the same apparatus but different materials and possibly different operating conditions. Attainment of this objective will depend on a full understanding of the mechanism of the absorption process. It can be achieved only after a large mass of data has been accumulated and a clear understanding of the effects and interrelations of the process variables has been developed as a result of critical examination of these data.

An important type of absorption apparatus is the packed tower. This consists of a shell of suitable material filled with packing, the purpose of which is to

increase the surface area of absorbent liquid exposed to the gas. The variety of packing materials which have been used is enormous, ranging from crushed rock and scrap metal to carefully designed ceramic and metal forms.

The behavior of equipment of this sort is relatively complex, since it involves the countercurrent movement of two fluid streams in direct contact. This means that, in addition to having to deal with effects resulting from the flow of each of the fluids over the packing material, one must consider the effects of each fluid stream on the flow behavior of the other.

As reported in the preceding paper in this series (7), the possibility that interaction between the two streams would affect the rate of mass transfer was considered. To test this possibility, an unusually extensive series of determinations of the mass-transfer coefficient for absorption of ammonia in water has been carried out, using one of the packings, No. 6295 Drip Point Grids, which had been employed in the earlier work. The effect of gas flow on the over-all and gas-film coefficients has been determined at six different liquid rates ranging from 1,900 to 15,000 lb./(sq.ft.)(hr.).

The two-film theory serves as the

basis for examining mass-transfer data. This theory is analogous to the theory of heat transfer by convection and assumes that the rate of absorption is controlled by the rate of diffusion of the solute through films of gas and liquid which are in viscous flow in the immediate vicinity of the liquid-gas interface. When Henry's law is valid for the equilibrium distribution of solute between gas and liquid, the over-all resistance may be expressed as the sum of individual film resistances as follows:

$$\frac{1}{K_{G}a} = \frac{1}{k_{G}a} + \frac{1}{Hk_{L}a} \quad (1)$$

The liquid-film coefficients can be determined conveniently by measurements of the desorption of slightly soluble gases. Direct determination of gas-film coefficients is difficult, and these are usually estimated from the over-all coefficients for the absorption of highly soluble gases for which the liquid-film resistance is relatively small, using Equation (1) and liquid-film coefficients estimated from the direct data for slightly soluble gases.

In most types of absorption equipment, the actual contact area cannot be determined so that the coefficients must be expressed on a volume basis and involve both a diffusion rate factor and an area factor. The diffusion rate factor k_d or k_L is presumed to be primarily a function of the thickness of the particular film involved and therefore of the turbulence of the fluid stream. The area factor a is probably a complex function of several variables. It is necessary to consider that it may be affected by the flow rates.

In one type of absorption equipment, the wetted-wall column, the contact area is fixed over a wide range of flow rates, so that this equipment permits examination of the effect of variables on the rate coefficient at fixed contact area. Some of the studies made on this type of equipment shed light on the behavior of

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Note: Table 1 which summarizes the data of this investigation is on file (Document 2729) with the American Documentation Institute, 1719 N Street, N.W., Washington, D.C. Price of microfilm, \$0.50, photoprints, \$0.50.

the gas film. A thorough study of the evaporation of pure liquids into air was made by Gilliland and Sherwood (2), who found that the following relationship applied:

$$\frac{D}{B_d} = 0.023(Re_d)^{0.83}(Sc_d)^{0.44} \quad (2)$$

It will be noticed that Equation (2) appears to be similar to the Dittus-Boelter equation for heat transfer by convection inside tubes:

$$Nu = 0.0225(Re)^{0.8}(Pr)^{0.4} \quad (3)$$

At the present time, however, it is believed that liquid-film resistance is involved in evaporation of liquids unless the liquid is fed at its adiabatic saturation temperature, so that the similarity in the constants of Equations (2) and (3) may be somewhat fortuitous.

In another wetted-wall tower investigation, Johnstone and Pifgord (4) found that the equation:

$$H_d/D = 7.63Re_d^{0.38}Sc_d^{0.67} \quad (4)$$

which may be transformed to:

$$D/B_d = 0.0328Re_d^{0.77}Sc_d^{0.83} \quad (5)$$

fitted their data for distillation and absorption. They noted that, because of the limited range of the Schmidt number covered by them, it was not possible to distinguish between $Sc_d^{0.83}$ as predicted by the Chilton-Colburn analogy with heat transfer and $Sc_d^{0.44}$ as found experimentally by Gilliland and Sherwood.

In any case, the similarity in form between Equations (2) and (5) and Equation (3) is strong evidence for the belief that there is a direct analogy between heat and mass transfer.

The apparatus and procedures used in this investigation have been described in the earlier papers of this series (6, 7). Since the structure of the packing used appears to be significant, this will be reviewed. The packing and distributor are illustrated in Figure 1. The packing consists of ceramic blocks $7\frac{1}{4}$ in. square $\times 6\frac{1}{4}$ in. high. Each block has fourteen slots $6\frac{1}{4}$ in. $\times \frac{1}{2}$ in. with semicircular ends, and there are eight half-slots on the outside edges. Short legs on the bottom of the block provide space for the redistribution of gas between each course of blocks, and integral "drip-points" along the bottom of the blocks guide the liquid dripping onto the lower courses largely onto the ceramic web between the slots and thereby assist in maintaining good liquid distribution. In the earlier work with this packing, a continuous-flue arrangement of the stacked blocks was found to be the most satisfactory. As a result of this structure, the packed section consists of a large number of short, narrow, practically rectangular wetted wall columns arranged in series-parallel.

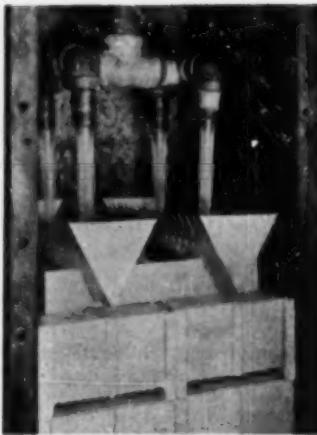


Fig. 1. No. 6295 Drip-Point Grid Packing.

Short spray sections separate the courses of blocks; however, these appear not to contribute quite so much to the effectiveness of the packing as the slots, since shortening the legs from $23/32$ in. to $11/32$ in. improved performance slightly and lengthening them to $1-23/32$ in. gave distinctly poorer performance.

Because of the nature of this packing, essentially complete wetting is obtained over a wide range of liquid flows so that the interfacial area and the packing surface are nearly equal. Also, since the free cross section in the slot sections is known, the actual Reynolds number of the gas can be calculated. A further point to be noted is that, while expansion and contraction occur between the courses of blocks, the gas flows through in nearly straight lines and seldom has any appreciable horizontal component of velocity.

Table I summarizes the data of the present investigation. Data reported for this packing by Molstad, McKinney, and Abbey (7) have also been employed in the correlations whenever possible.

Figure 2 shows the over-all mass-transfer coefficients as functions of the gas rate. Except for the data at a liquid rate of $10,550 \text{ lb./(sq.ft.) (hr.)}$, which appear to be high relative to the data taken at other liquid rates, a regular increase of K_{igd} with liquid rate is seen. Except as noted below, there is little evidence of variation of the slope of the K_{igd} vs. G lines with the liquid rate.

For the three highest liquid rates, as the gas rate is decreased below about 350 , the K_{igd} vs. G lines curve sharply downward from their normal slope of about 0.8 to one of 1.45 . Comparison of the curves with heat-transfer data, e.g., Figures 90 and 91 of McAdams (5), indicates that the behavior found is

characteristic of the change from turbulent flow to the upper limit of the transition region. This change occurs in the cases of heat transfer at a Reynolds number of about 8000 . In Figure 3 the change occurs at $Re = 1350$ or $G = 350$. Actually one would expect the lower limit of the transition region, where viscous flow commences, to be at $Re = 2100$ so that what appears to be the upper limit occurs at gas velocities far below those which would be expected.

The principal reason for believing the change to be that of the upper, rather than the lower, limit of the transition region is that the slope increases to 1.45 . In viscous flow, the slope of the K_{igd} vs. G plot would be one-third.

The most reasonable explanation of this behavior seems to be that the slots are so short that turbulence of the gas entering them is not damped out. Below the packing and in the space below the drop-points of each layer of packing, the 2100 to 8000 range of Reynolds number corresponds to G values of 73 to $280 \text{ lb./(sq.ft.) (hr.)}$. Therefore, the gas in these parts of the column was never in the viscous range and in most cases was well into the turbulent range. The ratio of length to four times the hydraulic radius, analogous to L/d for tubes, is only 4.3 . There have been pertinent comments on turbulence at low Reynolds numbers in short tubes in the literature on hydraulics, especially by Schweitzer (8), Davies and White (1), and Herschel (3).

Film coefficients calculated by subtracting from the experimental over-all resistances, using Equation (1), the liquid-film resistances calculated from oxygen desorption data for this packing are shown in Figure 3. All available data, a total of 83 points, were used in preparing this figure. After eliminating 11 of the points which deviated too greatly from a preliminary least-squares line, a final least-squares line was obtained. The maximum deviation of any of the 72 retained points from this line was 20.2% , and the average deviation was 7.9% . The distribution of the points about this line shows no trend with liquid rate. The equation of the line is:

$$k_{igd} = 0.0774G^{0.83} \quad (6)$$

It is of interest to compare this with the equations for wetted-wall columns. Substituting the appropriate constants into the Sherwood-Gilliland equation (1) and using four times the hydraulic radius instead of the diameter, the predicted equation for ammonia absorption is found to be:

$$k_{igd} = 0.0378G^{0.83} \quad (7)$$

Values found in the present investigation are therefore slightly over twice

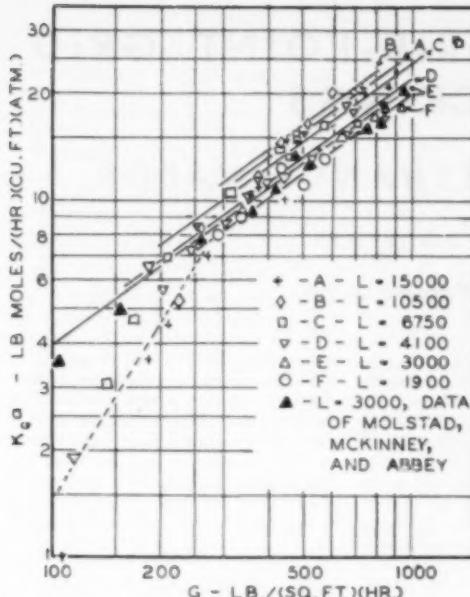


Fig. 2. K_{0a} vs. G for Ammonia Absorption with 2.25 ft. of No. 6295 Drip-Point Grid Packing.

those estimated for a wetted-wall tower. This is not surprising, since the Sherwood-Gilliland equation was based on experiments carried out in a wetted-wall column fitted with entrance and exit calming sections so that the equilibrium velocity distribution of the gas would be achieved in the wetted-wall section. Sherwood (9) reports data of Greenewalt for the absorption of water vapor by concentrated sulfuric acid in a wetted-wall column without a calming section, using several nozzles to introduce the gas. The K_{0a} values found ranged from two to eight times those predicted by the Sherwood-Gilliland equation, and qualitatively depended on the degree of turbulence introduced by the nozzle employed. A Venturi nozzle gave the lowest set of K_{0a} values and in this case the slope of the K_{0a} vs. G line changed from the value of 0.8 for turbulent flow to 0.33 for viscous flow at a G of about 230 lb./sq.ft.(hr.), compared with the calculated critical G of 600 lb./sq.ft.(hr.). In this case the change was direct with no evidence of transition flow. For the other nozzles used there was no evidence of either transition flow or of viscous flow down to a G of about 150 lb./sq.ft.(hr.).

The following conclusions may be drawn concerning gas-film coefficients for No. 6295 Drip-Point Grid packing:

- Gas-film coefficients vary with gas rate in the manner to be expected for a wetted-wall column with considerable entrance turbulence.

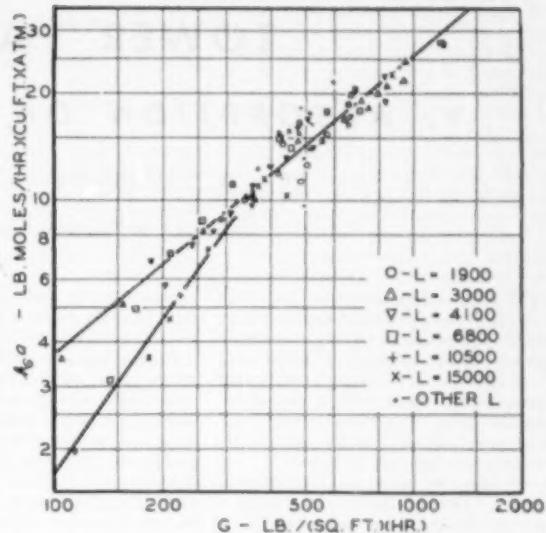


Fig. 3. K_{0a} vs. G for Ammonia Absorption with 2.25 ft. of No. 6295 Drip-Point Grid Packing.

- In the range of gas rates covered, up to 70% of the loading gas flow at the higher liquid flows, with liquid flows ranging from 2000 to 15,000 lb./sq.ft.(hr.), the gas-film coefficients are not affected by liquid flow.
- At gas rates of 350 lb./sq.ft.(hr.) or less, transition flow may occur. When it does, the gas-film coefficients are much lower than for the turbulent flow.

Notation

B_a = thickness of gas film, ft.
 c = specific heat, B.t.u./lb.
 D = diameter, ft.
 D_v = diffusivity, sq.ft./sec.
 G = mass velocity of gas, lb./hr. (sq.ft. of superficial cross-section)

H = Henry's law constant, lb. moles / (cu.ft.) (atm.)

h = film coefficient of heat transfer, B.t.u./hr. (sq.ft.) ($^{\circ}$ F.)

H_a = height of a gas-film transfer unit, ft.

k = thermal conductivity, B.t.u./hr. (sq.ft.) ($^{\circ}$ F.) (ft.)

K_a = over-all mass-transfer coefficient, area basis, lb. moles / (hr.) (sq.ft.) (atm.)

K_{0a} = over-all mass-transfer coefficient, volume basis-lb. moles / (hr.) (cu.ft.) (atm.)

k_{0a} = gas-film mass-transfer coefficient, area basis, lb. moles / (hr.) (sq.ft.) (atm.)

k_{0a} = gas-film mass-transfer coefficient, volume basis, lb. moles / (hr.) (cu.ft.) (atm.)

$k_L a$ = liquid-film mass-transfer coefficient, volume basis, lb. moles / (hr.) (cu.ft.) (lb. moles/cu. ft.)

L = liquid mass velocity, lb./sq. ft. (hr.)

m = hydraulic radius, cross section/wetted perimeter, ft.

Nu = Nusselt number, kD/μ

Pr = Prandtl number, $c\mu/k$

Re_g = Reynolds number of gas, DG/μ or $4mG/\mu$

Sc_g = Schmidt number of gas, μ/D

μ = viscosity, lb./ft. (hr.)

ρ = density, lb./cu.ft.

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PERFORMANCE OF DRIP-POINT GRID TOWER PACKINGS

V. ABSORPTION OF ETHANOL VAPOR

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THE preceding papers of this series (8, 9) have presented extensive data on the performance of a single semiplat packed column. Several packings have been employed in the experiments, which have covered pressure drops, oxygen desorption runs to determine liquid-film resistance, and ammonia absorption runs to determine gas-film resistance.

On many occasions it is of value to be able to predict the performance of a packed column in the absorption of an untested solute from performance tests with other solutes. Present absorption theory assumes that equilibrium determines the distribution of the solute between the gas and liquid phases at the interface and that the rate of transfer will be determined by either the rate of transfer through the gas to the interface or the rate of removal from the interface into the liquid or both. For physical absorption, the rate-controlling processes are considered to be diffusion of the solute through stagnant films of gas and liquid in the vicinity of the interface. The resistances of the gas and liquid films are apparently independent of each other and are governed by the turbulence and physical properties of the gas or liquid and by the diffusivity of the solute.

Of the two film resistances, the liquid film appears to be the better understood at the present time. Correlations for a number of packings were determined by Sherwood and Holloway (16), and these have been extended and confirmed by Molstad, Abbey, Thompson, and McKinney (8), Vivian and Whitney (20), and Deed, Schutz, and Drew (1) and proved valid even for very extreme extrapolation by Landau, Birchall, Joris, and Elgin (7).

The behavior in the case of the gas film has not been established so satisfactorily. It has therefore seemed de-

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Note: Table I, "Absorption of Ethanol Vapor," is on file with the American Documentation Institute (Document 2730), 1719 N Street, N.W., Washington 6, D.C. Material obtainable by remitting \$0.50 for microfilm, and \$0.80 for photocopies.

sirable to obtain additional data for systems in which major gas-film resistance is to be expected.

Ethanol vapor was selected as the first solute to be tested. The diffusivity in the gas phase is about 64% of that of ammonia, and the diffusivity in the liquid phase is about 55% of that of oxygen, so that there should be significant differences in the two film coefficients. The physical properties of ethanol and its solutions are well known. An analytical method which was simple and readily adaptable to the present problem was described in the literature. Finally, the high solubility of ethanol and the low vapor pressures of ethanol in equilibrium with its dilute aqueous solutions indicated that the gas film would be controlling.

The early runs of the investigation with No. 6295 Drip-Point Grid packing showed definite disagreement between the predicted and experimental coefficients, and showed in addition that the experimental coefficients varied more with liquid rate than would be predicted. An intensive study of ethanol absorption was therefore undertaken, with the hope that if the behavior of the system were fully explored, a satisfactory explanation of the behavior could be developed.

For each of the three ceramic packings used—No. 6295 Drip-Point Grids, 1-in. Raschig rings, and 1-in. Berl saddles—the variation of K_{Ld} with gas rate was studied at three or more different liquid rates, and in the case of the first two packings, some additional data of the variation of K_{Ld} with liquor rate at constant gas rate were taken to extend further the information on the effect of liquor rate. The range of gas rates covered has been from about 200 to 1200 lb./sq.ft. (hr.) for each packing. The range of liquid rates has been from 1,000 to 15,000 lb./sq.ft. (hr.) for No. 6295 Drip-Point Grids, from 300 to 13,000 lb./sq.ft. (hr.) for 1-in. Raschig rings, and from 400 to 4,000 lb./sq.ft. (hr.) for 1-in. Berl saddles.

Some data have also been taken to determine if K_{Ld} varies with the con-

centration of ethanol in the liquid. For a few of the runs complete temperature data were taken to permit calculation of the heat balances and qualitative explanation of the thermal effects found. Also, during a number of runs in which the small dumped packings were used, visual observations of the flow of liquid through the packed section were made.

Theory

The net rate of mass transfer may be regarded as inversely proportional to the sum of a series of individual resistances. For the case of physical absorption, consideration can generally be restricted to the resistances offered by stagnant films of gas and liquid in the vicinity of the interface, through which the solute must pass by diffusion. If Henry's law applies to the vapor-liquid equilibrium, an over-all mass-transfer coefficient may be expressed in terms of the two film coefficients as follows (see Notation):

$$\frac{1}{K_{Ld}} = \frac{1}{K_{Gd}} + \frac{1}{Hk_L a} \quad (1)$$

It is necessary to employ volume coefficients of the above form since the contact area in a packed column is a variable which cannot be measured. These are products of an area coefficient and the contact area per unit volume.

The area coefficients are evidently analogous to heat-transfer film coefficients and it is possible to write general expressions for them in the following forms:

$$k_{Gd}/D_d = a(Re_d)^m (Sc_d)^n \quad (2)$$

$$k_L a/D_L = a'(Re_L)^{n'}(Sc_L)^{0.5} \quad (3)$$

Since the correct value of D_d and the correct velocity to use in the Reynolds number are uncertain, as well as the contact area being unknown, simplified dimensional equations based on these are normally used:

$$k_{Gd} = \beta G^p D_d^{1-m} \quad (4)$$

$$k_L a/D_L = \beta' (L/\mu)^{p'} (Sc_L)^{0.5} \quad (5)$$

In these equations, the constants β and β' are necessarily characteristic of the packing and, for Equation (4), of the carrier gas as well. These constants

may also be affected by the type of liquid distributor used. Since both the contact area and the film thickness may be functions of the flow rates, ρ and ρ' may differ numerically from n and n' and may also vary with flow rates.

The value of m has not been determined with certainty. The analogy with heat transfer suggests that it should be 0.33; this has wide acceptance. Gilliland and Sherwood (5) found it to be 0.44 in their wetted-wall column investigation and Sherwood and Holloway (15) reported the value as 0.83 from the results of vaporization experiments in a column packed with half-inch rings. The range of the diffusivities of materials which can be used in absorption experiments is rather limited, so that it is difficult to obtain conclusive data. The first two values seem more probable than the last.

There is some evidence that absorption coefficients are functions of packed height. Van Krevelen and co-workers (19) have proposed that the constants a and a' and β and β' of the film coefficient equations vary as $(D_e/Z)^{1/2}$, based largely on their efforts to generalize these equations on the basis of published data. It will be shown here that this suggested correlation improves the agreement of the data of the present investigation for Berl saddles with data from other investigations in which the gas film controls. It was only with this one packing that a sufficient difference in packed height existed between the present work and other investigations with which it may be compared to cause significant difference in the coefficients.

A number of the recent investigations have been reviewed to determine if effects of packed height were noted and if they fitted the suggested correlation. So far as liquid-film controlled systems are concerned, there are no data which indicate that $k_{L,a}$ is affected by packed height. Sherwood and Holloway (16), investigating oxygen desorption, Deed, Schutz, and Drew (1), investigating carbon dioxide desorption, and Vivian and Whitney (20), investigating chlorine absorption, all ran experiments to check for possible effect of packed height. In each investigation, the greatest packed height used was about twice the least, and according to the correlation the coefficients for the lower height should have exceeded those for the higher by about 26 per cent. All three investigations showed that the coefficients were essentially independent of packed height.

For gas-film controlled systems, however, there appears to be good evidence that coefficients are affected by packed height. Parekh (10) pointed out four factors which were involved in the decidedly irregular effects of packed

height found in his investigation of humidification. These are:

- a. Effect of the spray section
- b. Unwetted area
- c. Liquid running down the tower wall
- d. Inaccuracy in measuring packed height

It should be possible to eliminate the first of these in absorption or desorption work, but the latter three effects must always be considered. Parekh's data correlate, but not to a convincing degree, with the suggested inverse cube-root relationship.

On the other hand, Fellinger's (4) ammonia absorption data show $K_{G,a}$ increasing, not decreasing, with packed height. This is probably accounted for by the unique method employed for introducing the gas. In order to eliminate absorption by spray below the packing the liquid level was held above the packing support and gas was introduced through a large number of small risers projecting through the liquid. This may have resulted in channelling of the gas in the lower part of the packing. Finally, Spector and Dodge (17) have reported data for absorption of carbon dioxide in caustic solutions, using packed heights of 7.8, 10, and 16 ft. The 7.8-ft. and 16-ft. runs, made with $\frac{1}{4}$ -in. rings in the same column, support the suggested relationship almost exactly. The 10-ft. runs were carried out with 1-in. saddles in a different column, so that their failure to agree with the other two series is to be expected.

The following conclusions as to the effect of packed height are all which seem justified at present:

- (a) $k_{L,a}$ is independent of packed height
- (b) $k_{G,a}$ is affected by packed height, being approximately inversely proportional to the cube root of packed height

Further investigation of the effect of packed height in gas-film controlled systems is evidently desirable.

Apparatus and Procedure

The apparatus and operating procedure have been described in detail in earlier papers of this series. Some modifications were made to permit the use of ethanol. The tower is $15\frac{1}{4}$ in. square (a square tower is used to accommodate the Drip-Point Grid packings). Packed heights of 1 to $2\frac{1}{4}$ ft. have been used. The weir distributor previously described was used; this was modified by adding a piece of angle iron on each side immediately below the weirs to prevent liquid from running down the outside walls of the troughs at low flow rates.

The ethanol was fed as liquid from an overhead storage vessel. It passed through a rotameter, then through the coil of an Excelso heater, where it was vaporized by condensing steam and into the blower inlet duct. It was found that the rotameter provided more consistent data on the concentration of ethanol in the inlet gas, as evidenced by better material balances, than did direct analysis of the gas. For this reason, the analysis of the inlet gas was omitted during the later runs, and the rotameter data were used to calculate all runs.

An additional modification was the installation of a line with a pump from the tower outlet to the liquid inlet. This permitted recycling any desired amount of the effluent, and as a result, operation at relatively high concentrations in the liquid phase.

Because of the extremely low concentrations encountered, a chemical method of analysis was employed. This was a modification of the procedure of Elliott and Dalton (3). Liquid samples were treated with excess standard $K_2Cr_2O_7$ in 50% H_2SO_4 , and a volume of concentrated H_2SO_4 equal to that of the liquid sample was added to maintain the acidity. The gas samples were bubbled through excess $K_2Cr_2O_7-H_2SO_4$ mixture, and the volume of the denuded gas was measured in a gas buret. It was found that by maintaining the high acidity, complete reaction was obtained quite rapidly without heating the solution. A few runs made with two gas absorption tubes in series confirmed that all the ethanol in the gas was dissolved in the first tube. The samples were allowed to stand at room temperature for 20 min. after treatment with $K_2Cr_2O_7$, as this length of time had proved adequate to permit completion of the oxidation of the ethanol by the chromic acid. Then the solutions were diluted with four volumes of water, excess solid KI was added, and after 5 min. standing in the dark, the liberated I_2 was titrated with standard $Na_2S_2O_3$.

It was found that the best results were obtained by using such a sample size and $K_2Cr_2O_7$ concentration that the total volume at the end of the oxidation step was not more than 30 ml. and by using a $Na_2S_2O_3$ solution having a normality one-fifth that of the $K_2Cr_2O_7$. The standard deviation of this analytical method was found to be $\pm 1.5\%$.

Discussion of Results

Altogether 231 runs were made. Of these, 150 have been retained, and the remaining 81 were rejected for various reasons.

Figures 1-4 present the results for 1-in. Raschig rings in the form of plots of $K_{G,a}$ vs. G , $K_{G,a}$ vs. L , $H_{G,a}$ vs. G , and $H_{G,a}$ vs. L , respectively. Since liquid

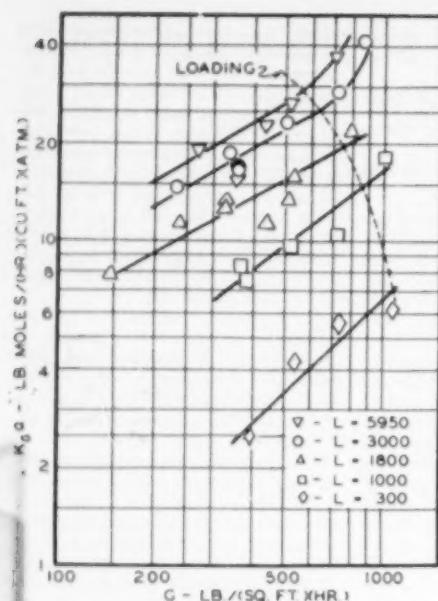


Fig. 1. $K_{G\alpha}$ vs. G for ethanol absorption with 2.0 ft. of 1-in. Raschig rings.

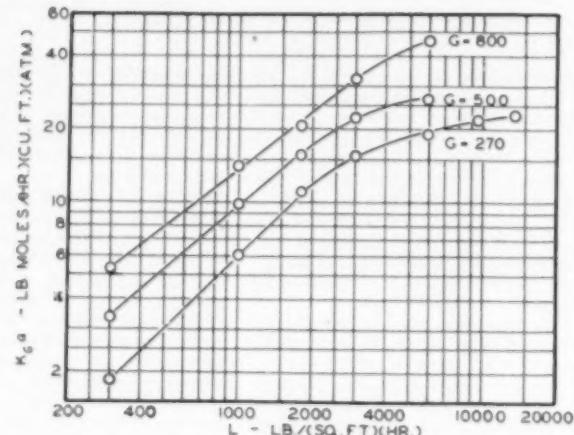


Fig. 2. $K_{G\alpha}$ vs. L for ethanol absorption with 2.0 ft. of 1-in. Raschig rings.

rate can be set at a desired value more precisely and more conveniently than gas rate; the general procedure used has been to select a liquid rate and then make several runs at varying gas rates. As a result, the graphs in which liquid rate is the independent variable are in most cases cross-plots.

The plot of $K_{G\alpha}$ vs. G shows generally normal behavior. The coefficient is a simple power function of G up to the loading point, and increases sharply in the loading region. It will be noted that the slopes of the lines increase as L decreases. The slope is about 0.6 for the three high liquid rates, but increases to 0.77 for $L = 1,000 \text{ lb}/(\text{sq ft})(\text{hr})$ and to 0.93 for $L = 300$.

The effect of liquid rate on $K_{G\alpha}$ shown in Figure 2 is obviously quite complex. In this case, in addition to the cross-plot data, points at liquid rates of about 10,000 and 13,500 $\text{lb}/(\text{sq ft})(\text{hr})$ have been determined for a gas rate of 270 $\text{lb}/(\text{sq ft})(\text{hr})$. This relatively low gas rate was used in extending the investigation to these high liquid rates so that there would be no possibility of approaching the loading point. It is evident that there is practically linear increase of $K_{G\alpha}$ with liquid rate up to 2,000 $\text{lb}/(\text{sq ft})(\text{hr})$ and that above 6,000 $\text{lb}/(\text{sq ft})(\text{hr})$, there is only slight increase. Representation of $K_{G\alpha}$ as a simple power function of liquid rate over the entire range is obviously incorrect.

During many of these runs, the observation window of the tower was placed

so that the flow of water within the packed section could be observed. Such observations can yield only qualitative information, but they do provide useful ideas for interpreting the absorption results. From the window, one can observe the flow as far as 2 or 3 in. into the tower with a dumped packing. The most evident fact is that channelling occurs at all liquid rates used. The amount of actively wetted area appears to increase with liquid rate from about 10-20% at the lowest liquid rate to 80-90% at the highest. The principal liquid streams follow as nearly vertical paths as possible, flowing mostly on the packing surface, but dripping off the packing at low points where an adjacent piece of packing is not available and falling as drops across the voids. The flow of the gas cannot be observed directly, but by observing the effects on the flowing liquid, it is possible to establish that there are probably definite channels carrying the bulk of the gas as well.

One of the obvious features is the interaction between the gas and liquid streams. This is most evident when the liquid is dropping across voids in the packed section. As the gas rate increases, the drops deviate more and more from their vertical course, due to transfer of kinetic energy from the gas. The usual result of this is to shorten the path of free fall. To the extent that a drop falls on a surface which would otherwise be dry, the active area is increased. This is probably the reason

why the slope of the $K_{G\alpha}$ vs. G plots is higher at low liquid rates; with only a small fraction of the area wetted, the effect of interaction in increasing the contact area would be expected to be greater than when most of the area is already active.

If the gas rate is increased sufficiently, a point is reached where the drops are blown horizontally across the voids. A substantial increase in holdup appears to result and this is evidently the loading point. Still further increase of the gas rate causes flooding, which is characterized by the appearance of very large slugs of liquid within the packing. These are often blown upward in the form of jets as the gas forces its way through narrow interstices of the packing.

A peculiar phenomenon can be observed when there is ethanol vapor in the gas stream. On a few pieces of packing which were covered with a thin film of water before introducing the ethanol, the wetted zone contracts to a small fraction of its original area as soon as the ethanol enters the packed section. The phenomenon was localized, occurring only where the very thin water films were. It may have caused a change in active area of 2% or 3%, however. It has been pointed out that the minimum liquid flow necessary to maintain a continuous liquid film on a wetted wall column is much higher when a solute such as ammonia or hydrogen chloride having a relatively high heat of absorption is used than when a material such as carbon dioxide

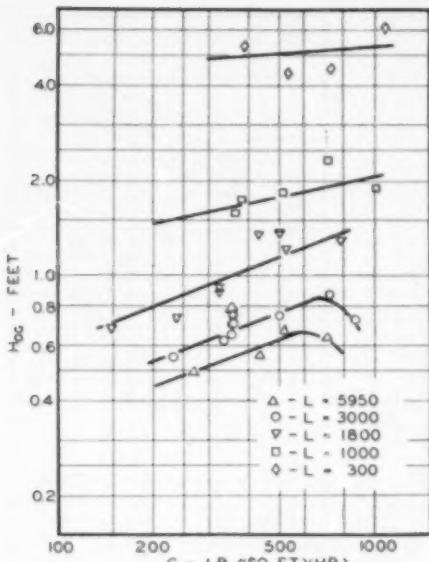


Fig. 3. H_{eq} vs. G for ethanol absorption with 2.0 ft. of 1-in. Raschig rings.

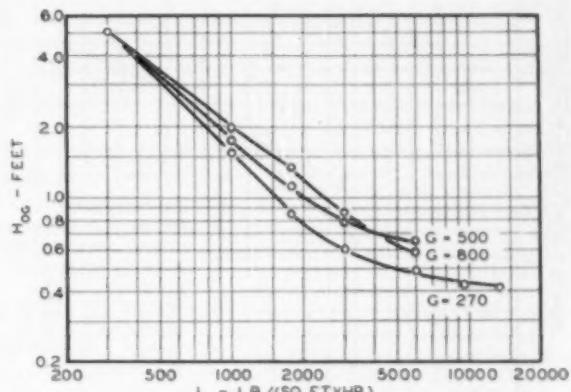


Fig. 4. H_{eq} vs. L for ethanol absorption with 2.0 ft. of 1-in. Raschig rings.

having a low heat of absorption is used (13). The phenomenon observed here is apparently analogous.

The important fact emphasized by the visual observations is that the active area in the packed section varies to a great degree with liquid rate and to a smaller extent with gas rate. Also, even at high liquid rates, total wetting is not achieved.

The above discussion of Figures 1 and 2 applies equally to Figures 3 and 4, which express similar data on the H_{eq} basis.

Figure 5 compares the coefficients for ethanol as a function of gas rate with the results of three other investigations—those of Molstad, McKinney, and Abbey (9) and of Fellinger (4) of ammonia absorption and that of Parekh (10) of humidification. Comparisons are made at a common liquid rate of 3,000 lb./sq.ft.(hr.).

The first of these was carried out in the same equipment used in the present investigation. As noted in the section on Apparatus and Procedure, a modification of the distributor was made during the present work, however. This modified distributor is believed to be decidedly more effective at low liquid rates than the original form. It should also be noted that the distribution obtained with the weir distributor probably varies to some extent with the gas rate. Gas flowing at high velocity past the liquid will tend to slow its fall somewhat so that at high gas rates the liquid jets issuing from the distributor weirs do not strike the top of the packing at the

same points as at low gas rates.

The latter two investigations were carried out in the laboratory of the Massachusetts Institute of Technology; the distributor described by Sherwood and Holloway (16) was employed by Parekh, and a distributor of different construction, but giving the same results, was used by Fellinger. These distributors divide the liquid into a number of equal streams which are delivered through tubes directly onto the top of the packing, so that a number of sections of the tower cross-section each receive the same fraction of the liquid fed regardless of the gas and liquid flow rates.

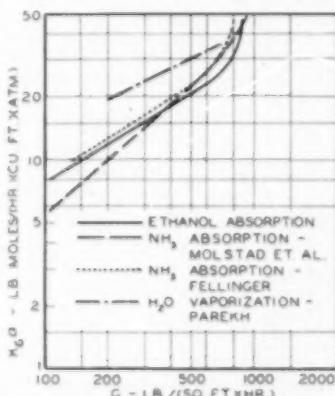


Fig. 5. Comparative coefficients as functions of gas rate for 1-in. Raschig rings. $L = 3000$ lb./sq.ft.(hr.).

Each of these sets of data shows that K_{eq} is a simple power function of the gas rate up to the loading point. For all the investigations except that of Molstad et al., the power is 0.5-0.6; for the latter it is 0.9. As will be seen, the higher exponent is probably accounted for by the behavior of the weir distributor in its original form at the liquid rate of 3,000 lb./sq.ft.(hr.) employed. It is evident that the coefficients for both the ammonia investigations become equal at high gas rates, when the gas-liquid interaction would cause the liquid to be thrown about as it left the distributor rather than simply dropping onto the top of the packing, so that the liquid distribution would be improved. The same general effect of gas rate has been found for the other packings as well.

Since Taecker and Hougen (18) have shown that K_{eq} varies as the 0.59 power of the gas rate for the evaporation of water from porous rings during the constant rate period, it is reasonable to believe that this power represents the effect of turbulence in the gas stream. A higher power would then represent either (a) progressively improving distribution as the gas rate is increased or (b) increased active area resulting from gas-liquid interaction within the packed section. In view of the visual observations, either or both of these effects might result as the gas rate is increased.

In Figure 6, a plot of K_{eq} vs. liquid rate at a constant gas rate of 500 lb./sq.ft.(hr.) is compared with calculated curves for the same conditions. In

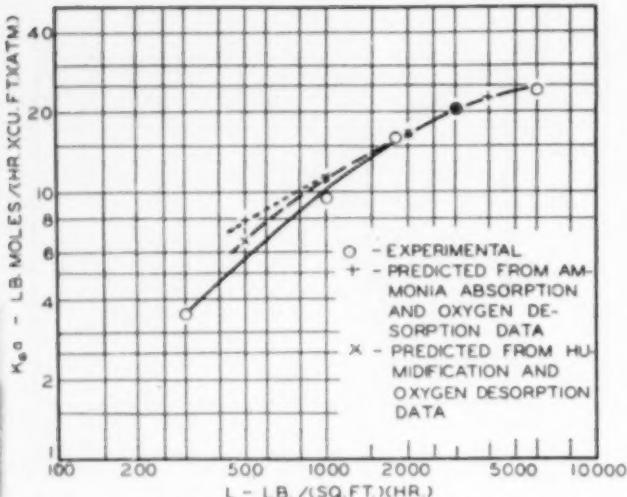


Fig. 6. Comparison of experimental and predicted coefficients for 1-in. Raschig rings. $G = 500$ lb./sq.ft. (hr.). Coefficients adjusted to packed height of 2.0 ft.

calculating the coefficients, the oxygen desorption data of Molstad, Abbey, Thompson, and McKinney (8) have been used to compute liquid-film coefficients and $k_{G,a}$ has been considered proportional to the 0.5 power of the liquid-phase diffusivity. Gas-film coefficients have been calculated from (a) the coefficients for humidification reported by Parekh (10) and (b) gas-film coefficients computed from the ammonia absorption data of Fellinger (4). All data have been adjusted to a packed height of 2.0 ft. according to the procedure discussed in the theory section of this paper; $k_{G,a}$ has been considered to vary as the 0.56 power of the gas-film diffusivity. The ammonia data of Fellinger have been preferred to those of Molstad, McKinney, and Abbey (9) because, first, the former data cover more completely the range of liquid rates involved in the present investigation and, second, the data of the latter investigation are low in the lower range of liquid rates covered because much of the liquid feed ran down the outside walls of the weir distributor troughs. This, of course, results in the liquid feed being concentrated along two lines on the top of the packing and accentuates channelling. As noted above, the distributor was modified during the present investigation to eliminate this fault.

The agreement between the experimental and calculated values is excellent

in the range of high rates and fair even at the low liquid rate of 500 lb./sq.ft. (hr.). The differences which are found at low liquid rates almost certainly result from differences in liquid distribution.

The experimental results for 1-in. Berl saddles are presented in Figures 7, 8, 9, 10. Liquid rates varying from 380 to 3,900 lb./sq.ft.(hr.) and gas rates varying from 240 to 1,200 lb./sq.ft.(hr.) have been used. A packed height of 1.0 ft. was employed. The effects of liquid and gas rates found are similar to those for Raschig rings. In the case of saddles, however, the loading point was not exceeded, so that the complications resulting from loading are not observed.

Figure 11 presents a comparison of

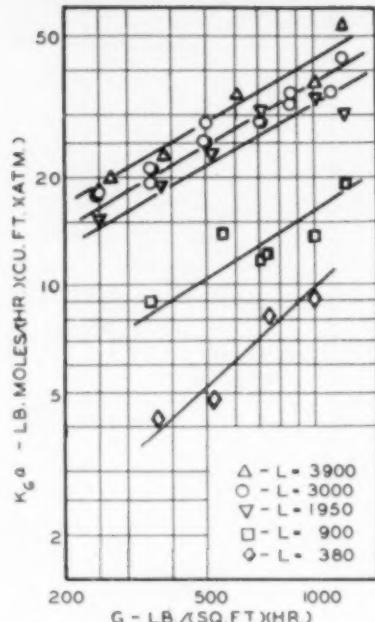


Fig. 7. $K_{G,a}$ vs. G for ethanol absorption with 1.0 ft. of 1-in. Berl saddles.

experimental and calculated coefficients for this packing. The same sources of film coefficient data and the same calculation techniques as were used in preparing Figure 6 have been employed here. The agreement in this case is not so good as was found for rings, especially in the range of low liquid rates. At $L = 500$ lb./sq.ft.(hr.), the value calculated from the ammonia absorption data is 83% high. However, at $L = 2000$ lb./sq.ft.(hr.) and above, the experimental and calculated coefficients agree within $\pm 10\%$ or better. The coefficients calculated from humidification data agree within $\pm 25\%$ or better throughout. Again, it seems reasonable to believe that the differences are largely a result of the behavior of the various liquid distributors used.

This figure presents strong evidence that the suggestion that $k_{G,a}$ varies inversely as the cube root of the packed height should be accepted. Application of this correction factor to the ethanol data to convert from the experimental packed height of 1.0 ft. to the height of 2.0 ft. used for the comparisons has resulted in displacing the curve down by 26%. If this had not been done, the agreement between the experimental and calculated coefficients would have been poor throughout. Without this correction the experimental coefficients for ethanol equal those for ammonia at $L = 2000$ lb./sq.ft.(hr.) and actually ex-

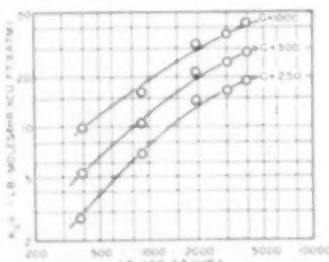


Fig. 8. $K_{G,a}$ vs. L for ethanol absorption with 1.0 ft. of 1-in. Berl saddles.

ceed the ammonia coefficients at higher liquid rates. This agreement is evidence in support of this method of correction for packed height.

Figures 12-15 present the experimental results for No. 6295 Drip-Point Grids and Figure 16 compares these with the ammonia absorption data of Molstad et al. (9) and of Parsly et al. (11). For this packing K_{Gd} was found to be a simple power function of both L and G over the entire range of flow rates used. Since the absorption surface of this packing consists largely of the walls of vertical slots through the packing, one would expect to find the effect of gas rate to be about that found for wetted-wall towers, i.e., the 0.8 power. The 0.84 power found shows this to be the case.

The effect of liquid rate with this packing is found to be much too great to be accounted for by theory. For ammonia absorption, Parsly et al. (11) found that k_{Gd} values computed for a very large amount of data for this packing could be correlated by a simple power function of the gas rate and were independent of the liquid rate. This indicates that the contact area remains essentially constant over the entire range of liquid rates used in the ammonia work—from 2,000 to 15,000 lb./sq.ft. (hr.). Estimates of the coefficients for ethanol from the ammonia absorption and oxygen desorption data indicated that K_{Gd} for ethanol absorption should vary as the liquid rate to only the 0.05 power. This is principally due to the very large value of the Henry's law constant for ethanol at low temperatures; it is 11.7 lb. moles/cu. ft. (atm.) at 25°C., compared to 3.5 for ammonia. The experimental results, however, show that K_{Gd} varies as the liquid rate to the 0.4 power.

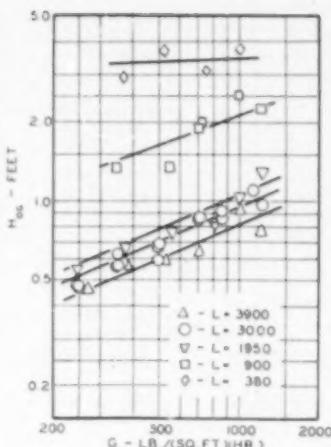


Fig. 9. H_m vs. G for ethanol absorption with 1.0 ft. of 1-in. Berl saddles.

It has not been possible to obtain any satisfactory explanation of this unexpectedly high effect of liquid rate. The simplest explanation would be that the contact area was increasing with liquid rate. However, the liquid rates employed were high, and it is difficult to believe that essentially total wetting was not obtained over most, if not all, of the range. It is not possible to observe the liquid flow through this packing, of course. Some of the other possibilities which have been considered are outlined below.

The first factor which suggested itself was that a concentration effect was involved. The practice of attempting to maintain about 1% ethanol in the gas entering the packed section, as had been done in the ammonia absorption work, was being followed. This meant that

there would be nearly a fivefold concentration change in the liquid leaving the packed section as the liquid rate varied from 3,000 to 15,000 lb./sq.ft. (hr.)—the range in which most of the experiments on this packing were made. Accordingly, experiments were carried out to determine if any effect of concentration could be found.

Runs to determine the effect of liquid concentration were made with the No. 6295 Drip-Point Grid packing. The varying concentration was obtained by changing the amount of ethanol fed to the inlet air stream. Using the maximum effective range of the alcohol rotameter, it was possible to obtain a tenfold range of concentrations, from 0.04 to 0.4%, in the liquid leaving the packed section. This is ample to determine if K_{Gd} is sufficiently affected by liquid concentration to account for the effect of liquid rate noted above. These data indicated no effect of concentration. A few similar tests were made with Berl saddles. (In this case, for $L = 3,000$ lb./sq.ft. (hr.), groups of three points were taken at several of the gas rates, using three different ethanol feed rates.) Again, no effect of concentration was found.

It also seemed possible, since there were evidences of surface tension lowering in the foaming of the effluent liquid, that the behavior might result from surface effects. It could be the result of either a significant change in the holdup or of adsorption of ethanol in the surface. Experiments were made to determine if significant changes in holdup could occur as a result of surface tension lowering (14). However, a 60% decrease in surface tension increases holdup by only 25%, and as a surface tension lowering of not more than a few per cent occurs in the ab-

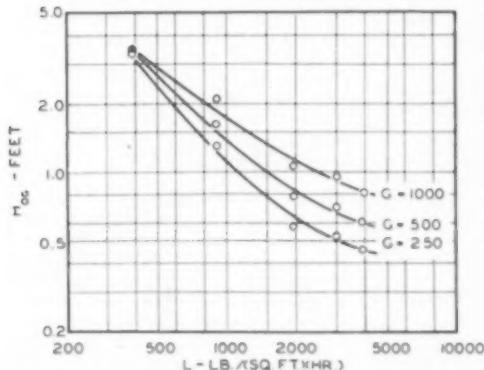


Fig. 10. H_m vs. L for ethanol absorption with 1.0 ft. of 1-in. Berl saddles.

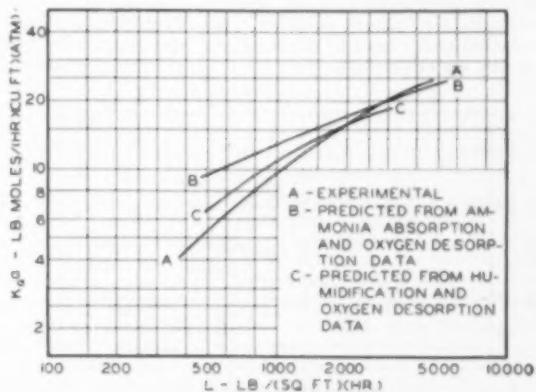


Fig. 11. Comparison of experimental and predicted coefficients for 1-in. Berl saddles.

$G = 500$ lb./sq.ft. (hr.). Coefficients adjusted to packed height of 2.0 ft.

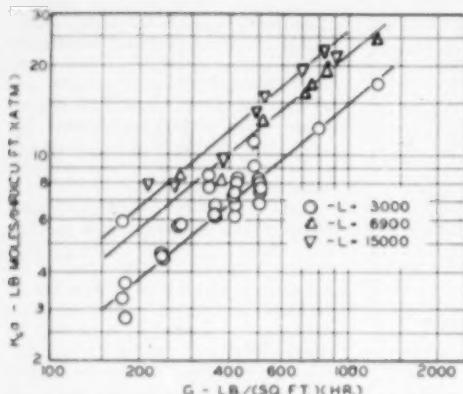


Fig. 12. $K_{L\theta}$ vs. G for ethanol absorption with 2.25 ft. of No. 6295 Drip-Point Grids.

sorption runs, this possibility seems ruled out. The surface adsorption hypothesis also seems improbable, since the surface excess should be very low in the concentration range encountered and also because such a mechanism should be affected by concentration.

Another possibility which has been considered is that a reaction mechanism is responsible for the abnormal effect of liquid rate observed. Vivian and Whitney (20) have shown that the rate of hydration of chlorine affects $K_{L\theta}$ for this solute, and Whitney and Vivian (21) have shown that a similar effect occurs in sulfur dioxide absorption. It is well known that ethanol exists as a hydrate in solution, so that a liquid-phase reaction must occur during its absorption.

There are no means of testing the hypothesis that reaction is the source of the abnormal behavior of the grid packing during ethanol absorption. There are no data in the literature reporting either equilibrium or velocity constants for ethanol hydration, and these constants cannot be calculated indirectly from other data.

There are good reasons for believing that the hydration reaction would not be the explanation. First, $K_{L\theta}$ increases more rapidly than expected with liquid rate. In the case of the chlorine and sulfur dioxide work, it was found that $K_{L\theta}$ increased less rapidly with liquid rate than predicted assuming instantaneous reaction. Second, a hydration reaction of this type is believed to have a low energy of activation so that the velocity constant should be very high.

Thus, no one of the four explanations considered—liquid distribution, concentration, surface effects, and reaction effects—provides a satisfactory explanation of the large effect of liquid rate on the coefficients for the Drip-Point Grid packing. Careful study of the data fails to disclose any other reasonable alternative.

It should be pointed out that the No. 6295 Drip-Point Grid packing showed unusual behavior in the liquid-film investigation. The coefficients for oxygen desorption with this packing were of about the same magnitude as those for ring and saddle packings. Since the gas-film coefficients obtained by am-

monia absorption measurements were only about half as great as those for the other two packings, this may indicate unique liquid-film behavior for this packing.

It has not been possible to determine film coefficients for ethanol absorption. The effects of liquid rate found indicate that $k_{L\theta}$ values predicted from oxygen desorption might be erroneous. An alternative method for estimating the values of the film coefficients would be to use a method analogous to the Wilson (22) method of determining heat-transfer film coefficients. This involves plotting $1/K_{L\theta}$ vs. $1/G^n$, based on Equation (1). The intercept, theoretically, will be $1/Hk_{L\theta}$. There are several objections to this procedure. First, in heat-transfer work it has been found that the method is satisfactory only when one film resistance greatly predominates, such as when there is a condensing vapor. Second, an arbitrary assumption as to the value of the exponent, n , on G is involved. Straight lines can be put through the data using a range of values of n of, for example, 0.5 to 0.9 making it practically impossible to select the

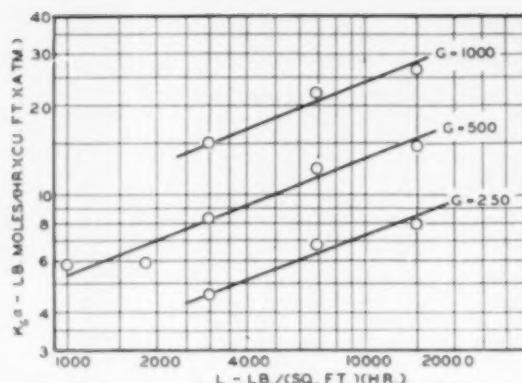


Fig. 13. $K_{L\theta}$ vs. L for ethanol absorption with 2.25 ft. of No. 6295 Drip-Point Grids.

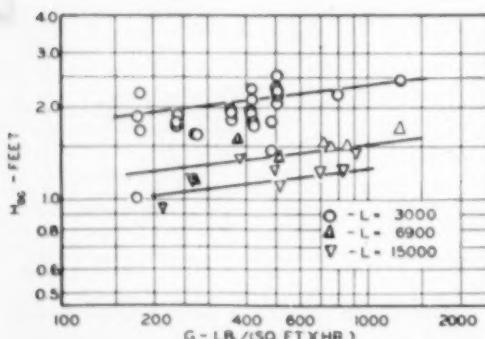


Fig. 14. $H_{L\theta}$ vs. G for ethanol absorption with 2.25 ft. of No. 6295 Drip-Point Grids.

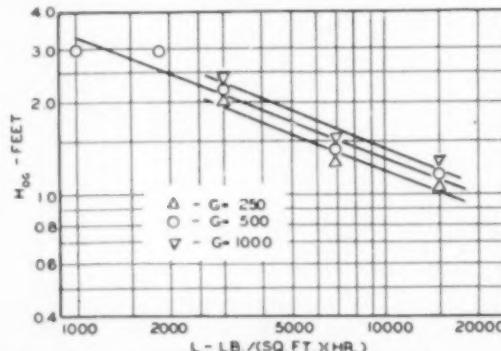


Fig. 15. $H_{L\theta}$ vs. L for ethanol absorption with 2.25 ft. of No. 6295 Drip-Point Grids.

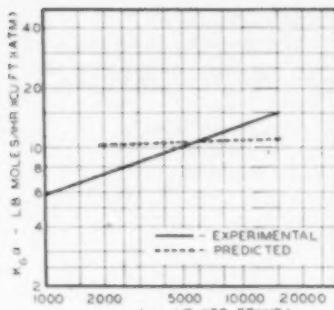


Fig. 16. Comparison of experimental and predicted coefficients for ethanol absorption with 2.25 ft. of No. 6295 Draft-Print Grids.

$$G = 500 \text{ lb./(sq.ft.) (hr.)}$$

true value of the exponent. Because the "liquid-film coefficients" found would vary with the value of n selected, results obtained in this manner are open to doubt. It must also be noted that this method assumes that the contact area is independent of the gas rate at any given liquid rate. Results of the present investigation indicate that this is not necessarily true.

Thermal Effects

During the later part of the present investigation, the question of the possible existence of a temperature maximum in the column was raised (12). In order to gain some insight into the cause of this maximum, complete temperature data were taken on three of the runs. The one showing the most pronounced maximum temperature was run No. 205, for which the data and calculations are given in Table "A."

These over-all heat balances are satisfactory, considering the small temperature changes involved. Random fluctuations in the temperature of the water entering probably account for part of the discrepancies. In addition, although the actual temperature rise exceeds the calculated rise in every case, this excess is accounted for in part by the fact that the water temperature was in all cases less than the room temperature, so that heat transfer through the column walls from the surroundings would be expected.

Heat balances over the lower spray section indicate that the temperature maximum found in the experiments is actually impossible. The only possible cause for the temperature maxima indicated above would be that humidification was occurring in this section to such an extent that the heat of vaporization of the water transferred into the air was equal to the sum of (a) the heat of absorption of the ethanol taken up and, (b) the heat given up in cooling the water to the extent measured. The heat

TABLE A.
THERMAL DATA AND CALCULATIONS FOR RUN NO. 205

| | |
|---|-------------------------|
| $G = 393 \text{ lb./(sq.ft.) (hr.)}$ | 6.53 lb./(sq.ft.) |
| $L = 403 \text{ lb./(sq.ft.) (hr.)}$ | 1.25 lb./(sq.ft.) (hr.) |
| $X = 0.0162 \text{ lb. ethanol/lb. H}_2\text{O}$ | 2.47 lb./(sq.ft.) (hr.) |
| Absorption | 2.81 lb./(sq.ft.) (hr.) |
| Absorption above packed section | 6.53 lb./(sq.ft.) (hr.) |
| Absorption in packed section | 14.0° C. |
| Absorption below packed section | 15.3° C. |
| Temperatures: | |
| H ₂ O entering from main | 6.5° C. |
| H ₂ O entering packed section | 14.0° C. |
| H ₂ O leaving packed section | 15.3° C. |
| H ₂ O leaving column | 15.3° C. |
| Air in blower duct | 36.0° C. |
| Air 3 ft. above packed section | 11.0° C. |
| Laboratory air—dry bulb | 25.8° C. |
| wet bulb | 16.1° C. |
| Miscellaneous: | |
| Barometer | 777 mm. Hg. |
| 1 c. of ethanol at 5° C. | 41.8 B.t.u./lb. |
| 15° C. | 412 B.t.u./lb. |
| 20° C. | 409 B.t.u./lb. |
| Heat of mixing of ethanol solutions: | |
| 7 cal./g. solution for 0.1 wt. fraction at 0° C. | |
| 3 cal./g. solution for 0.1 weight fraction at 50° C. | |
| 3.1 cal./g. solution for 0.1 weight fraction ethanol estimated from above for 15° C. | |
| Sources of thermodynamic data: | |
| Heat of mixing and heat of vaporization—Dodge (9) | |
| Humidity chart—Walker, Lewis, McAdams, and Gilliland (22) | |
| Enthalpy-composition chart for humid air—Hougen and Watson (6) | |
| Estimate of heat lost by air: | |
| Calculated humidity of entering air: 0.0042 lb. H ₂ O/lb. bone dry air. | |
| Exit air is assumed unsaturated. | |
| Enthalpy of entering air | 22.0 B.t.u./lb. |
| Enthalpy of air leaving | 21.0 B.t.u./lb. |
| Change in enthalpy of air | 7.0 B.t.u./lb. |
| Heat lost by air = enthalpy change × air rate $= 7.0 \times 393 = 2750 \text{ B.t.u./(hr.) (sq.ft.)}$ | |
| Heat release due to ethanol condensation | |
| Rate of absorption × heat of vaporization $6.53 \times 412 = 2890 \text{ B.t.u./(hr.) (sq.ft.)}$ | |
| Heat release due to heat of mixing: | |
| Weight of solution formed × heat of mixing for 0.1 wt. fraction × (actual wt. fraction)/0.1 $(403)(4.9 \times 1.8)(0.016/0.1) = 570 \text{ B.t.u./(hr.) (sq.ft.)}$ | |
| Total heat release: $2750 + 2890 + 570 = 6210 \text{ B.t.u./(hr.) (sq.ft.)}$ | |
| Expected temperature rise: $6210/(403 \times 1.8) = 8.6^\circ \text{C.}$ | |
| Actual temperature rise: $15.3 - 6.5 = 8.8^\circ \text{C.}$ | |
| Summarized results for the other 2 runs for which heat balances have been calculated are: | |
| Run No. 200 | |
| $G = 516 \text{ lb./(sq.ft.) (hr.)}$ | 7.0° C. |
| $L = 965 \text{ lb./(sq.ft.) (hr.)}$ | 13.0° C. |
| Temperature of water entering column | 10.5° C. |
| Temperature of water at bottom packing | 10.5° C. |
| Temperature of water leaving column | 10.5° C. |
| Actual over-all temperature rise | 3.5° C. |
| Calculated over-all temperature rise | 2.8° C. |
| Run No. 209 | |
| $G = 352 \text{ lb./(sq.ft.) (hr.)}$ | 8.0° C. |
| $L = 5950 \text{ lb./(sq.ft.) (hr.)}$ | 4.8° C. |
| Temperature of water entering column | 4.5° C. |
| Temperature of water at bottom of packing | 4.5° C. |
| Temperature of water leaving column | 4.5° C. |
| Actual over-all temperature rise | 1.5° C. |
| Calculated over-all temperature rise | 1.1° C. |

balances show that, except at the bottom of the spray section for Run No. 205, the calculated enthalpy driving force is negative. Therefore dehumidification, rather than humidification, must have occurred in Runs 200 and 209 and no temperature maximum could have existed. Some humidification could have occurred in Run 205, but not enough to account for the temperature maximum found.

The only alternative is to conclude that the temperature maximum did not actually exist. It would be possible, of

course, for this to be the case if the sample withdrawn from the bottom-of-packing were not representative of the bulk of the liquid passing this level. Strong evidence that the sample is not representative in many cases can be deduced from the experimental data. Measurements to determine the temperature change of the spray section were made for 36 of the runs. These were largely the runs for Berl saddles at $L = 2000 \text{ lb./(sq.ft.) (hr.)}$ or less, and for rings at $L = 1000 \text{ lb./(sq.ft.) (hr.)}$ or less; four were runs made with rings

at $L = 6000$ lb./sq.ft.(hr.). The temperature of the water leaving the packed section was greater than that of the water leaving the column in twenty-five of these runs, less in five and the same in six. At the same time, there was very good reason to believe that the concentrations of ethanol found in this bottom-of-packing sample were too high in many of these runs. In eleven, the concentration of ethanol in the bottom-of-packing sample was equal to or greater than the concentration in the bottom-of-tower sample, so that there is no doubt that these samples were not representative. All eleven showed temperature maxima. In thirteen of the runs, the concentration in the bottom-of-packing sample is less than in the bottom-of-tower sample, but still appears high, and in the other twelve runs the concentrations seem to be of the right order. Ten of the former runs and only four of the latter showed temperature maxima. There is, therefore, a distinct correlation between the apparent validity of the bottom-of-packing sample and the absence of a temperature maximum.

The difficulty of obtaining a valid bottom-of-packing sample is probably a result of the channeling which has been observed in many of the runs. Due to the channeling, concentrations in the liquid are not uniform across the cross section of the column at any given level and obtaining even an approximately valid sample is largely a matter of chance. The discrepancies probably would be most marked at low liquid rates.

Conclusions

Results for the ring and saddle packings support the current theory that absorption coefficients can be predicted for an untried system from film coefficient data for systems whose behavior is known, on the basis of diffusivity and vapor-liquid equilibrium data. Deviations from predicted behavior at low liquid rates only point up the importance of initial liquid distribution in determining the performance of packed columns, and emphasize that this factor becomes most critical in the range of very low liquid rates where total wetting of the packing is not even approached.

Results of the present investigation do not give any indication as to whether the 0.56 power of the diffusivity determined experimentally by Gilliland and Sherwood (5) or the 0.67 power suggested by heat-transfer analogies should be used for predicting gas-film coefficients.

It has not been possible to establish a satisfactory explanation of the behavior

of the Drip-Point Grid packing as a function of liquid rate. This type of packing apparently gives its most favorable performance in liquid-film controlled systems. More data are needed for its behavior to be fully understood.

The apparent large effect of packed height for gas-film controlled systems is of great importance. Published performance data are almost invariably for short laboratory columns, while the designer must sometimes consider columns of many times that height. The result is that it is easily possible to underdesign a column even though the laboratory data indicate that an ample safety factor has been used. Since the evidence available up to the present time is contradictory, more investigation of this subject is desirable. It would be well to have data showing the effect of varying the packed height for several solutes and also for several different types of liquid distributing systems.

Present results also indicate that in extrapolation to liquid rates below the experimental range, it is probably best to consider that K_{qa} varies directly as the liquid rate. This may frequently be conservative, but would be very close to the behavior shown by both the ring and saddle packings in the present investigation as the liquid rate was decreased below 1,000 lb./sq.ft.(hr.).

Notation

- D_e = equivalent diameter, ft.
- D_L = diffusivity of solute in liquid phase, sq.ft./hr.)
- D_g = diffusivity of solute in gas phase, sq.ft./hr.)
- G = superficial mass velocity of gas, lb./sq.ft.(hr.)
- H = Henry's law constant, lb. moles/(cu.ft.)(atm.)
- H_{og} = height of over-all transfer unit based on gas-phase driving force, ft.
- k_u = gas-film coefficient on an area basis, lb. moles/(hr.)(sq.ft.)(atm.)
- k_f = liquid-film coefficient on an area basis, lb. moles/(hr.) (sq.ft.)(lb. mole/cu.ft.)
- k_{uf} = gas-film coefficient on a volume basis, lb. moles/(hr.)(cu.ft.)(atm.)
- k_{fa} = liquid-film coefficient on a volume basis, lb. moles/(hr.)(cu.ft.)(lb. mole/cu.ft.)
- K_{qa} = over-all mass-transfer coefficient on a volume basis based on gas-phase driving force, lb. moles/(hr.)(cu.ft.)(atm.)
- L = superficial mass velocity of liquid, lb./sq.ft.(hr.)
- m, m' = constants
- n, n' = constants

- ρ, ρ' = constants
- Re = Reynolds number, dimensionless
- Sc = Schmidt number, dimensionless
- Z = packed height, ft.
- a, a' = constants
- β, β' = constants
- μ = viscosity, lb./ft.(hr.)

SUBSCRIPTS:

- G = gas-phase
- L = liquid-phase

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STUDIES OF GAS-BUBBLE FORMATION

CALCULATION OF INTERFACIAL AREA IN BUBBLE CONTACTORS

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Two types of formation and rising of gas bubbles in liquids can be distinguished, viz. bubbles formed separately or in series (chain-bubbling).

In the first case the diameter of the bubbles is independent of the flow rate and proportional to the cube root of the orifice diameter. Chain-bubbling takes place above a certain critical flow rate. Here bubble diameters are independent of the orifice diameter and increase with increasing flow rate.

Dimensionless expressions are derived, enabling a rapid calculation of critical gas velocity, bubble diameter, rising velocity and interfacial area.

In many chemical engineering operations bubble contactors are used in order to obtain an intimate gas-liquid contact. In such an apparatus gas bubbles are forced to ascend through a column of liquid. One well-known representative of these bubble contactors is the ordinary plate column. The prediction of efficiencies for such apparatus under arbitrary conditions will be possible only if the fundamental phenomena governing the formation and ascending of bubbles and the rate of interphase mass transfer are known.

Application of the well-known rate equation of mass transfer:

$$N = k(\Delta y)_m A \quad (1)$$

to absorption or rectification measurements affords values of the product kA , which is directly proportional to the interfacial surface area. This shows the importance of knowing the value of A in any arbitrary case. It is obvious that A is a function of the diameter and the ascending velocity of the bubbles. Moreover, the value of k itself will again be a function of diameter and ascending velocity of the bubbles.

For both reasons the possibility to calculate bubble diameters and ascending velocities is of considerable importance for the prediction of efficiencies of bubble towers.

Though the results of several experimental investigations on this subject have been published, a general survey and systematic treatment of the existing

data are not yet available, as far as is known. The present study intends to give a first approach to this systematic treatment. As the problem is complicated, it will be simplified in this approach by the following limitations:

1. Bubbles are formed at a single orifice with the opening upwards.
2. Diameter of liquid column is so large that the wall does not influence ascending bubbles.
3. Liquid column does not contain any obstacles (packing material, etc.)
4. Liquid in the column is not circulated except by the action of the bubbles themselves.

In practice none of these conditions will be completely fulfilled. Further investigations will be necessary but as long as they fail, results obtained in this paper may be used as a first approximation.

Experiments

Measurements of Bubble Diameter. Gas was allowed to flow with a constant rate through a capillary tube with known diameter into a column of liquid. The flow rate of the gas was measured by means of a calibrated flow meter.

For measuring the average bubble diameter, a number of bubbles was counted and caught in a calibrated vessel, so that the total volume could be determined.

As all these experiments (in coopera-

tion with J. Huiskamp) were performed within the region of separate bubble formation (see later), it was observed that the bubbles were formed quite regularly, each of them having the same volume and ascending at a constant distance.

Experimental results are summarized in Table 1.

Measurements of Gas Holdup. These measurements (in cooperation with C. J. van Hooren) were performed by bubbling gas through a column of the desired dimensions, originally completely filled with liquid. The gas holdup equals the quantity of liquid overflow; the latter could easily be gathered and measured. Gas flow rate was again measured with a calibrated flow meter.

Behaviour of the bubbles was much less regular than in the above-mentioned experiments on separate bubbles. Yet it could be observed that just above the capillary inlet tube the bubbles ascended in a vertical line, almost touching each other (like a pearl necklace). During ascending, however, the bubbles deviated from the original vertical line; the higher the gas flow rate, the greater these deviations. At the highest flow rates, bubbles were even subdivided during ascending.

Experimental results are summarized in Table 2.

For each experiment the holdup per unit column height H_h has been calculated. Our experiments show H_h to be independent of diameter and height of the column.

There are two factors that might cause H_h to vary with the column height:

1. Higher gas pressure at the bottom of the column. For the highest columns used in our experiments this might result in a variation of about 2 per cent in the ascending velocity. This variation falls within the limits of exactitude of these experiments.

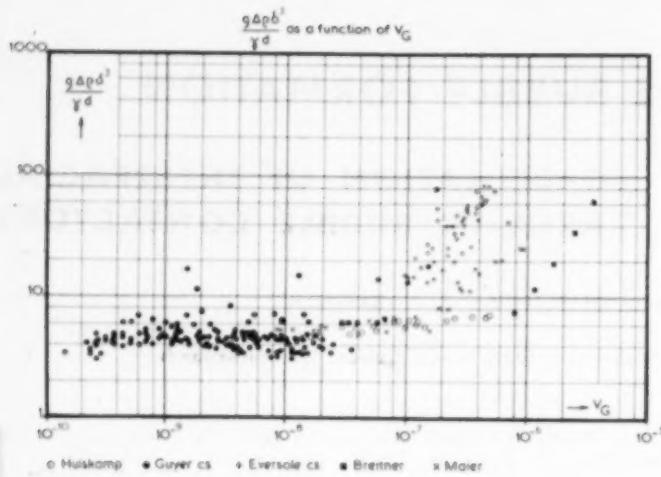


Fig. 1.

- The ascending velocity is zero at the bottom of the column. Calculation shows, however, that a constant ascending velocity has already been reached after ascending less than 0.1 mm.

Wall effects might result in an influence of the column diameter, but in these experiments such an influence was not observed when varying the column diameter from 1 to 3 in.⁶ This is in contradistinction to the results obtained by O'Brien and Gosline (5). It may be remembered, however, that these investigators used bubbles of about the same dimensions as the column diameter.

As can be seen from Table 2, the gas holdup proves to be nearly independent of the diameter of the capillary inlet tube. The larger capillary diameters ($d > 3$ mm.) give deviations which are caused by internal wetting of the capillary. This can be prevented to a great extent by application of an internal paraffin coating.

All experiments have been performed with air except No. 47-52 of Table 2, in which hydrogen was used. An influence of the kind of gas used could not be observed.

Formation of Separate Gas Bubbles

Theoretical Equation. Using some simplifying assumptions, it is possible to derive a relationship for the diameter of gas bubbles, formed on orifices. These assumptions are:

- Complete wetting of orifice.
- Spherical shape of bubble.

* For larger column diameters measurement of liquid overflow became too inaccurate.

The bubble diameter remained constant up to a certain flow rate. At a further increase of the flow rate the bubble diameter increased.

The same result was obtained by Maier (9) using several orifice diameters.

A series of experiments in our own laboratory is shown in Table I. All these experiments prove to be in accordance with theory.

Further mention is made of the experiments of Reiny and Seemann (13) in which the orifice opening was directed downwards. Their results are approximately in accordance with the conclusions of this paper. Finally the experiments of Owens (11), being less accurate, reasonably agree with the other data.

Summarizing conclusions drawn from the experimental data it may be stated that for each series of experiments bubble formation principally agrees with theory up to a certain critical value of the flow rate. Above this limit the bubble diameter increases with the flow rate. In the second part of this paper further attention will be paid to this phenomenon. Beforehand we want to summarize the literature on ascending velocities of gas bubbles.

Ascending Velocities of Separate Gas Bubbles. Experiments on this subject have been published (7, 8, 4, 3, 10, 15, 1, 14, 12).

In accordance with the limitations mentioned, attention will be paid only to those experiments where the influence of walls does not play a part.

In Figure 2 the ascending velocity v_s has been plotted against the bubble diameter for all experiments with water. Although results of the investigators differ somewhat from each other, Figure 2 shows clearly that for the ascending of bubbles three regions can be distinguished. Each branch of Figure 2 represents a certain type of gas bubble:

- Small bubbles (<1.5 mm.). These have a spherical shape and ascend in a straight line. The ascending velocity increases with increasing bubble diameter.
- Medium-size bubbles (1.5-6 mm.). In this region the bubbles are visibly deformed; they ascend with a spiral movement. The irregular character of the movement causes spreading of the data in Figure 2.
- Large bubbles (>6 mm.). The bubbles again ascend in a straight line but they are largely deformed and finally they obtain a more or less mushroom-like shape. Bubble velocity increases slightly with increasing diameter.

Some investigators also performed ex-

periments with other liquids. For some liquids the second region did not exist; this will doubtless depend on physical properties of the liquid (viscosity and surface tension). Further it can be concluded from these experiments that for the last region the ascending velocity is nearly independent of the physical properties of the liquid.

There is need for more experimental data in this field.

Formation and Ascending of Gas Bubbles in Series

Interpretation of Phenomenon and Working Hypothesis. It was stated previously that below a certain critical value of the flow rate bubble formation is in accordance with the theoretically derived expression.

Above this limit the bubble diameter increases with the flow rate. This phenomenon can be explained by the fact that at high flow rates the formation of bubbles is hindered by the presence of preceding bubbles. This will become obvious from the following argumentation. When for a given orifice the flow rate is gradually increased, the bubble diameter will remain constant at first. To a constant bubble diameter belongs a constant ascending velocity. This means that the distance between two successive bubbles is inversely proportional to the frequency of bubble formation. It is clear that this distance can never be smaller than the bubble diameter. So above a certain value of the flow rate it is not possible to transport the actual quantity of gas by means of bubbles of the theoretical diameter. The only possibility is that the bubbles become greater. In this way the phenomenon of increasing bubble diameter above a certain value of the flow rate can be explained qualitatively.

Now before a quantitative relationship between flow rate and bubble diameter can be derived, a working hypothesis must be chosen about the mechanism of bubble formation. Our hypothesis is the following:

The bubbles become just as large as necessary to transport the supplied quantity of gas, which means that two succeeding bubbles just do not touch each other.

In contradistinction to the formation of separate bubbles we call this type of bubble formation: "formation of bubbles in series" or "chainlike bubble formation."

The hypothesis enables the derivation of a quantitative relation for the bubble diameter, for any shape of the bubbles. For the ideal case that the bubbles are spherical the equation is:

$$U_g = \frac{\pi}{6} \delta^2 \frac{v_b}{\delta} = \frac{\pi}{6} \delta^2 v_b \quad (3)$$

TABLE I.—20° C., AIR
Column diameter = 6 cm.

| No. | Column Height cm. | Liquid | ρ g./cu.cm. | σ dynes/cm. poise | γ dyn./cm. | d. mm. | F_d cu.cm./ sec. | δ mm. | $\frac{\pi \delta^2 \rho}{6}$ |
|---------------|----------------------|----------------|---------------------|--------------------------------|----------------------|-----------|--------------------------|-----------------|-------------------------------|
| <i>I</i> a | 23.4 | water | 1.0 | 1.0 | 72 | 9.5 | 0.475 | 7.94 | 7.1 |
| | 23.4 | water | 1.0 | 1.0 | 72 | 9.5 | 0.383 | 7.86 | 6.9 |
| | 23.4 | water | 1.0 | 1.0 | 72 | 9.5 | 0.256 | 7.72 | 6.6 |
| | 23.4 | water | 1.0 | 1.0 | 72 | 9.5 | 0.126 | 7.60 | 6.3 |
| <i>II</i> a | 17.3 | water | 1.0 | 1.0 | 72 | 9.5 | 0.486 | 7.81 | 6.8 |
| | 17.3 | water | 1.0 | 1.0 | 72 | 9.5 | 0.380 | 7.72 | 6.6 |
| | 17.3 | water | 1.0 | 1.0 | 72 | 9.5 | 0.257 | 7.78 | 6.7 |
| | 17.3 | water | 1.0 | 1.0 | 72 | 9.5 | 0.129 | 7.65 | 6.4 |
| <i>III</i> a | 12.2 | water | 1.0 | 1.0 | 72 | 9.5 | 0.483 | 7.80 | 7.0 |
| | 12.2 | water | 1.0 | 1.0 | 72 | 9.5 | 0.386 | 7.80 | 6.8 |
| | 12.2 | water | 1.0 | 1.0 | 72 | 9.5 | 0.255 | 7.72 | 6.6 |
| | 12.2 | water | 1.0 | 1.0 | 72 | 9.5 | 0.124 | 7.56 | 6.2 |
| <i>IV</i> a | 5.8 | water | 1.0 | 1.0 | 72 | 9.5 | 0.476 | 7.86 | 6.9 |
| | 5.8 | water | 1.0 | 1.0 | 72 | 9.5 | 0.370 | 7.80 | 6.6 |
| | 5.8 | water | 1.0 | 1.0 | 72 | 9.5 | 0.231 | 7.65 | 6.3 |
| | 5.8 | water | 1.0 | 1.0 | 72 | 9.5 | 0.118 | 7.50 | 6.2 |
| <i>V</i> a | 23.4 | water | 1.0 | 1.0 | 72 | 1.5 | 0.153 | 4.02 | 3.9 |
| | 23.4 | water | 1.0 | 1.0 | 72 | 1.5 | 0.0544 | 3.98 | 3.7 |
| | 23.4 | water | 1.0 | 1.0 | 72 | 1.5 | 0.0294 | 3.96 | 3.6 |
| | 5.8 | water | 1.0 | 1.0 | 72 | 1.5 | 0.142 | 3.98 | 3.7 |
| <i>VI</i> a | 5.8 | water | 1.0 | 1.0 | 72 | 1.5 | 0.089 | 3.94 | 3.5 |
| | 5.8 | water | 1.0 | 1.0 | 72 | 1.5 | 0.0385 | 3.90 | 3.4 |
| | 5.8 | water | 1.0 | 1.0 | 72 | 1.5 | 0.0167 | 3.06 | 4.7 |
| <i>VII</i> a | 23.4 | transf. oil | 0.877 | 28 | 35 | 1.5 | 0.0346 | 3.10 | 4.9 |
| | 23.4 | transf. oil | 0.877 | 28 | 35 | 1.5 | 0.0800 | 3.27 | 6.2 |
| | 23.4 | transf. oil | 0.877 | 28 | 35 | 1.5 | 0.0572 | 3.18 | 5.2 |
| | 23.4 | transf. oil | 0.877 | 28 | 35 | 1.5 | 0.0196 | 3.06 | 4.7 |
| <i>VIII</i> a | 5.8 | transf. oil | 0.877 | 28 | 35 | 1.5 | 0.0426 | 3.13 | 5.0 |
| | 5.8 | transf. oil | 0.877 | 28 | 35 | 1.5 | 0.0867 | 3.38 | 6.3 |

For bubbles of any other shape an analogous formula can be given, the constant ($\pi/6$) being somewhat different.†

Ascending Velocity for Bubbles in Series. For applying the above-derived formula $U_g = \pi/6\delta v_b$ to those experiments in which the bubble diameter increases with the flow rate, v_b as well as U_g and δ must be known. Unfortunately only U_g and δ have been measured in any of those experiments.

Now we may expect a distinct relationship between δ and v_b . For separate bubbles, this relationship has been discussed in a previous chapter. At first we tried to use this same relationship for chainlike bubble formation. It proved, however, that the ascending velocity for a series of bubbles can be quite different from that for separate bubbles of the same diameter, due to the interaction of the bubbles. So before the experiments of bubble formation can be interpreted, the relation between ascending velocity and bubble diameter for series of bubbles must be known. Now it is possible to measure the ascending velocity as a function of the flow rate in chainlike bubble formation, using an indirect method, namely by measuring the gas holdup per unit of height, H_k , as the

* In deriving this equation it is assumed that two succeeding bubbles are exactly vertically above each other (like a pearl necklace). Little deviations from vertical ascending will not have much influence.

† In the following when using the term diameter of bubble diameter of a sphere with a volume equal to bubble volume is meant.

ascending velocity is then: $v_b = U_g/H_k$.

Unfortunately we were not able to measure bubble diameter simultaneously in these experiments. So two kinds of experimental results are available:

- Experiments on bubble formation giving δ as a function of U_g (performed by the investigators mentioned in Chapter I).
- Hold-up measurements, giving v_b as a function of U_g (experiments performed by the authors).

In order to prove the validity of assumptions made an inverse method shall be used: assuming that the formula $U_g = \pi/6\delta v_b$ can be applied v_b from U_g and δ for the experiments of the first type can be calculated; also δ from U_g and v_b can be calculated for the other experiments. Relations between v_b and δ will coincide if the assumption is valid.

Application to Experiments. In order to include data for any kind of liquid the relation between v_b and δ must be expressed in a dimensionless form. By analogy with the well-known theory of the movement of solid spheres through fluids, dimensionless quantities to be used are:

$$Ex = \frac{g\delta\rho}{v_b^2\rho} \quad \text{and} \quad Re = \frac{v_b\delta\rho}{\mu} \quad (4)$$

In Figure 3 these two quantities have been plotted against each other for the various experimental results available:

- For the experiments of bubble for-

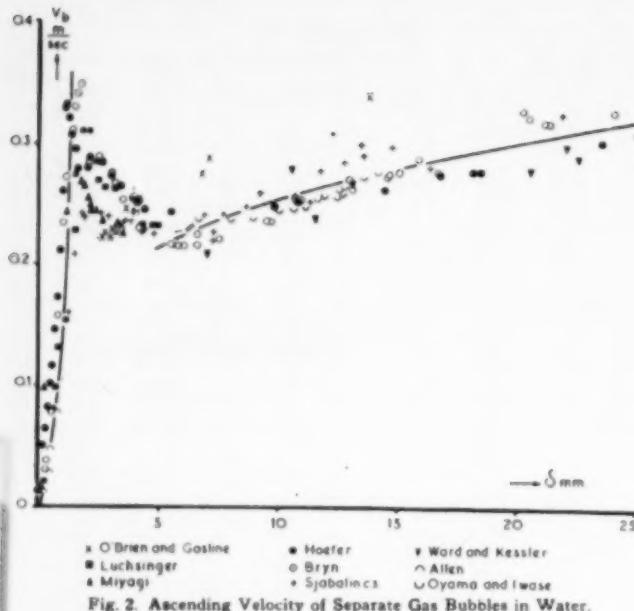


Fig. 2. Ascending Velocity of Separate Gas Bubbles in Water.

- mation of Eversole, Wagner and Stackhouse, Maier, Breitner, Guyer and Peterhans as far as they refer to chainlike bubble formation.
 b. Measurements of gas holdup already mentioned. Data are given in detail in Table 2.
 c. Some experiments on the ascending of separate bubbles, mentioned before.
 d. The curve for the movement of solid spheres.

It is obvious from Figure 3 that the relation between Ex (so-called expansion group) and Re can be divided into two regions: In the streamline region Ex is inversely proportional to Re . The curve for chainlike formation coincides with those for solid spheres and for separate gas bubbles. In the turbulent region Ex is independent of Re for series of bubbles; the points can be approximately represented by a horizontal line with Equation $Ex = 2$. Separate bubbles, however, deviate largely from bubbles in series, especially in the transition region. Neither does the curve for solid spheres coincide with that for series of bubbles in the turbulent region.

Obviously the relationship between Ex and Re for series of bubbles can be represented by a broken line as shown in Figure 3. For the streamline part the equation is

$$Ex = \frac{18}{Re}$$

for the turbulent part $Ex = 2$

The agreement between data of groups *a* and *b* for chain bubbling allows the use of our working hypothesis.

Prediction of Critical Flow Rate. The above-mentioned correlation between V_a , δ and v_b makes it possible to predict the critical flow rate below which the bubble formation will lead to the theoretical diameter.

a. Turbulent Region. The horizontal branch of Figure 3 can be represented by the equation:

$$\frac{\delta g \Delta \rho}{v_b^2 \rho} = 2$$

With

$$V_a = \frac{\pi}{6} \delta^2 v_b \quad (5)$$

this gives

$$\delta = \left(\frac{721 \rho^2 \mu}{\pi^2 g \Delta \rho} \right)^{1/3} \quad (6)$$

At the critical flow rate this value of δ must equal the theoretical value for separate bubble formation:

$$\delta = \left(\frac{6yd}{g \Delta \rho} \right)^{1/3} \quad (7)$$

So the critical value of V_a is given by:

$$\frac{V_a^6 g^3 \rho^2 \Delta \rho^2}{\gamma^5 d^5} = 20 \quad (8)$$

b. Streamline Region. Here

$$\frac{\delta g \Delta \rho}{v_b^2 \rho} = 18 \frac{\mu}{v_b \delta \rho}$$

(Fig. 3), so that

$$\delta = \left(\frac{18 \times 6 V_a \mu}{\pi g \Delta \rho} \right)^{1/4} \quad (9)$$

At the critical flow rate this value of δ must equal again the theoretical value for separate bubbles, so that after substitution we get:

$$\frac{V_a^6 g^3 \rho^2 \Delta \rho}{\gamma^5 d^5} = 0.03 \quad (10)$$

Accordance between predicted and observed values for the critical flow rate for the experiments available is evident from Figure 4, where those series from Figure 1 have been reproduced for which at the same orifice the flow rate has been varied at both sides of its critical value. The critical value predicted from the above formula is indicated by a little vertical line for each series. This, again, is a proof for the validity of our working hypothesis.

Practical Applications. The purpose of our study was to obtain knowledge about bubble diameter, ascending velocity and area of gas-liquid interphase for any arbitrary case of gas-bubbling through a liquid. Of course, the limitations formulated in the beginning of the paper must be regarded; on the other hand, relations derived above will also hold for the case that the contactor contains more than one orifice, if only these orifices are so wide apart that they do not influence each other.

For circumstances which do not agree with the limitations set, the formulae derived may serve as a first approximation.

For practical use three diagrams have been constructed (to be used for water and diluted aqueous solutions only); for convenience sake we used English units.

a. Bubble Diameter As a Function of the Flow Rate (Fig. 5). As derived before, for chainlike bubble formation

$$\delta = \left(\frac{72\rho}{\pi^2 g \Delta \rho} \right)^{1/3} V_a^{0.6} \quad (11)$$

giving one single line in Figure 5 independent of the orifice diameter.

For the formation of separate bubbles

$$\delta = \left(\frac{6yd}{g \Delta \rho} \right)^{1/3} \quad (12)$$

independent of the flow rate. In Figure 5 this relation is represented by a number of horizontal lines, each for a certain orifice diameter. For a given orifice and increasing flow rate the horizontal line corresponding to that orifice diameter must be followed first until the line for serial formation is

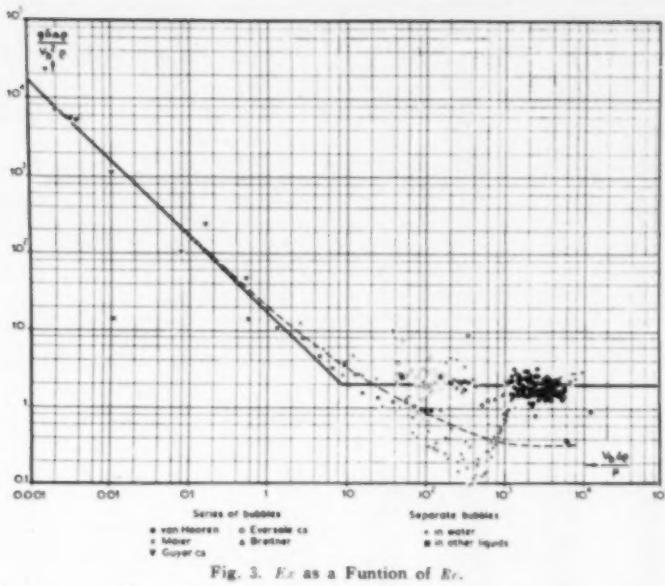


Fig. 3. $\frac{g\Delta\rho\delta^2}{v_b^2 P}$ as a Function of Re .

reached, which is then followed for further increase of flow rate.

b. *Ascending Velocity* (Fig. 6). For bubbles formed in series,

$$v_b = \left(\frac{g\delta}{2} \right)^{\frac{1}{2}} \quad (13)$$

again giving one single line independent of orifice diameter. For separate bubbles, to each orifice diameter belongs a certain value of bubble diameter; from Figure 2 the corresponding ascending velocity can be found. As in Figure 5, this gives a horizontal line for each orifice diameter. The critical gas velocity can be read from Fig-

ure 5. The ascending velocity at this critical point is always smaller than that for separate bubbles of the same diameter. This means that there must be a more or less sudden change in ascending velocity in the neighborhood of the critical flow rate. In Figure 6 this sudden change is approximated by dotted lines.

c. *Area of Gas-Liquid Interphase* (Fig. 7). Total interfacial area will be proportional to the height of the column and thus the area per unit column height, A_h , must be used.

Figure 7 has been derived from Figures 5 and 6 by using the relations:

$$\text{For chainlike formation: } A_h = \pi\delta$$

$$\text{For separate bubbles: } A_h = \frac{61'g}{v_b\delta}$$

Figure 7 being derived from Figure 6, the sudden change in ascending velocity at the critical flow rate causes an equivalent change in A_h , again being approximated by dotted lines.

For any arbitrary liquid three analogous figures can be constructed in the way described above.

Examples:

Find bubble diameter, bubble velocity and contact area:

- a. For orifice diameter $d = 0.1$ in., flow rate $V_G = 0.06$ cu.ft./hr. In each of the three Figures 5, 6 and 7 the separate line for $d = 0.1$ in. must be used, giving:

$$\delta = 0.195 \text{ in.}$$

$$v_b = 0.76 \text{ ft./sec.}$$

$$A_h = 0.009 \text{ sq.ft./ft.}$$

- b. For the same orifice diameter and $V_G = 1$ cu.ft./hr. In each of the three figures the single line for chainlike formation must be used, giving:

$$\delta = 0.34 \text{ in.}$$

$$v_b = 0.68 \text{ ft./sec.}$$

$$A_h = 0.086 \text{ sq.ft./ft.}$$

Acknowledgment

The authors are indebted to J. Huiskamp and C. J. van Hooren for their assistance in performing experiments and calculations.

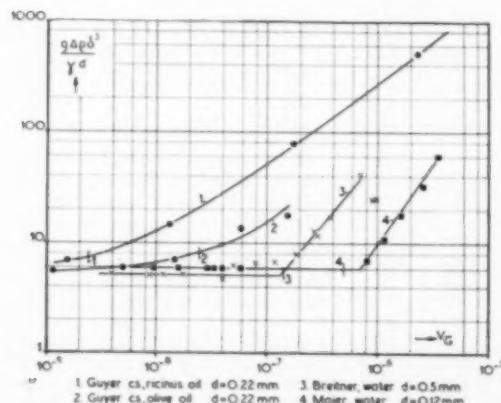


Fig. 4. Critical Flow Rate.

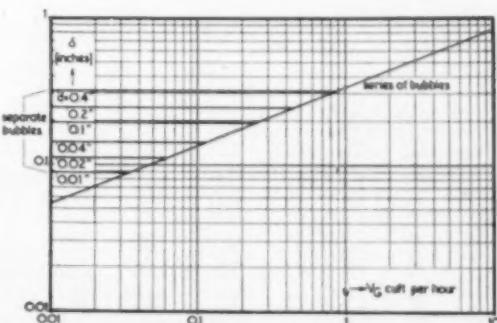


Fig. 5. δ as a Function of V_G for Water.

TABLE I—EXPERIMENTS WITH WATER (20° C.)^aHeight of column—66 cm. Diameter of column 4.7 cm.^b

| No. | d mm. | F _G cm./sec. | H _s cm./sec. | V _b cm./sec. | g mm. | Re | Ex |
|-----|----------|----------------------------|----------------------------|----------------------------|----------|------|-----|
| 1 | 2.0 | 20.4 | 0.757 | 26.9 | 12.02 | 3200 | 1.6 |
| 2 | 2.0 | 10.55 | 0.379 | 27.8 | 8.51 | 3800 | 1.1 |
| 3 | 2.0 | 15.14 | 0.682 | 23.2 | 13.41 | 3500 | 2.3 |
| 4 | 2.0 | 21.9 | 0.864 | 26.3 | 15.85 | 3300 | 2.0 |
| 5 | 2.0 | 20.9 | 1.392 | 27.9 | 16.31 | 4600 | 2.1 |
| 6 | 2.0 | 22.2 | 0.832 | 29.1 | 12.61 | 3700 | 1.5 |
| 7 | 2.0 | 28.9 | 1.120 | 25.8 | 14.63 | 3800 | 2.2 |
| 8 | 2.0 | 7.50 | 0.348 | 21.6 | 8.15 | 3800 | 1.7 |
| 9 | 2.0 | 16.94 | 0.758 | 23.3 | 12.02 | 2700 | 2.4 |
| 10 | 2.0 | 30.8 | 1.105 | 27.9 | 14.53 | 4100 | 1.8 |
| 11 | 2.0 | 15.20 | 0.698 | 21.9 | 11.55 | 3500 | 2.4 |
| 12 | 2.0 | 28.3 | 1.013 | 27.9 | 13.92 | 3900 | 1.8 |
| 13 | 2.0 | 42.2 | 1.435 | 29.4 | 16.55 | 4900 | 1.9 |
| 14 | 2.0 | 51.4 | 1.546 | 33.2 | 17.18 | 5700 | 1.5 |
| 15 | 2.0 | 56.4 | 1.772 | 31.8 | 18.38 | 5800 | 1.8 |
| 16 | 2.0 | 10.00 | 0.462 | 21.6 | 9.39 | 2600 | 2.0 |
| 17 | 2.0 | 11.94 | 0.576 | 20.7 | 10.49 | 2200 | 3.4 |
| 18 | 2.0 | 6.28 | 0.334 | 19.1 | 7.99 | 1500 | 2.3 |
| 19 | 2.0 | 4.58 | 0.200 | 18.3 | 6.91 | 1300 | 2.0 |
| 20 | 1.2 | 21.0 | 0.758 | 28.9 | 12.03 | 3500 | 1.4 |
| 21 | 1.2 | 24.1 | 0.772 | 31.5 | 12.14 | 3800 | 1.2 |
| 22 | 1.2 | 11.94 | 0.477 | 25.0 | 9.54 | 2400 | 1.5 |
| 23 | 1.2 | 15.50 | 0.545 | 28.6 | 10.20 | 2900 | 1.2 |
| 24 | 1.2 | 4.17 | 0.197 | 21.2 | 6.13 | 1300 | 1.3 |
| 25 | 1.2 | 8.13 | 0.334 | 24.9 | 7.9 | 2000 | 1.3 |
| 26 | 1.2 | 38.3 | 1.156 | 33.3 | 14.83 | 4900 | 1.3 |
| 27 | 6.0 | 42.5 | 1.294 | 22.8 | 15.72 | 5200 | 1.4 |
| 28 | 6.0 | 12.92 | 0.538 | 24.0 | 10.14 | 2400 | 1.7 |
| 29 | 6.0 | 16.11 | 0.621 | 25.9 | 10.89 | 2800 | 1.6 |
| 30 | 6.0 | 7.25 | 0.318 | 24.5 | 7.79 | 1900 | 1.3 |
| 31 | 6.0 | 9.44 | 0.409 | 23.1 | 8.84 | 2000 | 1.6 |
| 32 | 6.0 | 14.60 | 0.545 | 27.5 | 10.20 | 2800 | 1.3 |
| 33 | 6.0 | 26.4 | 0.649 | 27.2 | 11.61 | 3700 | 1.8 |
| 34 | 6.0 | 45.5 | 1.378 | 35.5 | 16.22 | 5400 | 1.3 |
| 35 | 6.0 | 8.47 | 0.318 | 26.6 | 12.27 | 3200 | 1.7 |
| 36 | 6.0 | 5.83 | 0.258 | 22.6 | 7.02 | 1600 | 1.4 |
| 37 | 6.0 | 20.0 | 0.667 | 20.0 | 11.29 | 3400 | 1.2 |
| 38 | 6.0 | 28.6 | 0.924 | 31.0 | 13.29 | 4100 | 1.4 |
| 39 | 6.0 | 17.22 | 0.806 | 28.4 | 10.76 | 3100 | 1.3 |
| 40 | 6.0 | 13.89 | 0.845 | 28.6 | 9.62 | 2800 | 1.2 |
| 41 | 2.0 | 19.44 | 0.636 | 30.6 | 11.02 | 3400 | 1.2 |
| 42 | 2.0 | 10.8 | 0.387 | 31.2 | 13.73 | 4300 | 1.4 |
| 43 | 2.0 | 14.60 | 0.545 | 27.5 | 10.20 | 2800 | 1.3 |
| 44 | 2.0 | 45.5 | 1.378 | 35.5 | 16.22 | 5400 | 1.3 |
| 45 | 2.0 | 8.47 | 0.318 | 26.6 | 12.27 | 3200 | 1.7 |
| 46 | 2.0 | 5.83 | 0.258 | 22.6 | 7.02 | 1600 | 1.4 |
| 47 | 2.0 | 20.0 | 0.667 | 20.0 | 11.29 | 3400 | 1.2 |
| 48 | 2.0 | 28.6 | 0.924 | 31.0 | 13.29 | 4100 | 1.4 |
| 49 | 2.0 | 17.22 | 0.806 | 28.4 | 10.76 | 3100 | 1.3 |
| 50 | 2.0 | 13.89 | 0.845 | 28.6 | 9.62 | 2800 | 1.2 |
| 51 | 2.0 | 9.44 | 0.333 | 28.3 | 7.97 | 2300 | 1.0 |
| 52 | 2.0 | 8.89 | 0.356 | 25.0 | 8.25 | 2100 | 1.3 |
| 53 | 2.0 | 7.50 | 0.379 | 19.8 | 8.51 | 1700 | 2.1 |
| 54 | 2.0 | 10.83 | 0.424 | 25.5 | 9.00 | 2300 | 1.4 |
| 55 | 2.0 | 15.85 | 0.575 | 27.5 | 10.48 | 2900 | 1.4 |
| 56 | 2.0 | 9.72 | 0.462 | 24.0 | 9.39 | 2600 | 2.1 |
| 57 | 2.0 | 6.39 | 0.318 | 20.1 | 7.79 | 1600 | 1.9 |
| 58 | 2.0 | 8.72 | 0.273 | 17.3 | 7.22 | 1300 | 2.4 |
| 59 | 2.0 | 32.2 | 1.120 | 28.8 | 14.63 | 3200 | 1.7 |
| 60 | 2.0 | 17.8 | 1.135 | 33.3 | 14.73 | 4900 | 1.3 |
| 61 | 2.0 | 19.72 | 0.711 | 27.7 | 11.65 | 3200 | 1.5 |
| 62 | 2.0 | 27.5 | 0.923 | 29.8 | 13.28 | 4000 | 1.5 |
| 63 | 2.0 | 2.80 | 0.303 | 32.5 | 7.61 | 2500 | 0.7 |
| 64 | 2.0 | 6.00 | 0.303 | 22.9 | 7.61 | 1700 | 1.4 |
| 65 | 2.0 | 9.44 | 0.394 | 24.0 | 9.68 | 2100 | 1.5 |
| 66 | 2.0 | 13.75 | 0.515 | 26.7 | 9.92 | 2700 | 1.4 |
| 67 | 2.0 | 25.3 | 0.773 | 32.7 | 12.15 | 4000 | 1.1 |
| 68 | 2.0 | 29.4 | 0.909 | 29.0 | 13.18 | 3800 | 1.5 |
| 69 | 2.0 | 28.6 | 0.910 | 31.1 | 13.18 | 4100 | 1.3 |
| 70 | 2.0 | 9.72 | 0.424 | 22.9 | 9.00 | 2100 | 1.7 |
| 71 | 2.0 | 28.6 | 0.910 | 31.1 | 13.18 | 4100 | 1.3 |
| 72 | 2.0 | 9.72 | 0.424 | 22.9 | 9.00 | 2100 | 1.7 |
| 73 | 2.0 | 28.6 | 0.910 | 31.1 | 13.18 | 4100 | 1.3 |
| 74 | 2.0 | 28.6 | 0.910 | 31.1 | 13.18 | 2800 | 1.6 |
| 75 | 2.0 | 28.6 | 0.910 | 31.1 | 13.18 | 2100 | 2.1 |
| 76 | 2.0 | 2.80 | 0.356 | 28.9 | 11.14 | 2700 | 1.9 |
| 77 | 2.0 | 2.80 | 0.356 | 18.5 | 8.28 | 1600 | 2.4 |
| 78 | 2.0 | 2.80 | 0.356 | 28.6 | 12.18 | 3500 | 1.8 |
| 79 | 2.0 | 2.80 | 0.356 | 17.8 | 8.11 | 1400 | 2.5 |
| 80 | 2.0 | 2.80 | 0.356 | 28.9 | 11.14 | 2700 | 1.9 |
| 81 | 2.0 | 2.80 | 0.356 | 22.0 | 10.25 | 2200 | 0.9 |
| 82 | 2.0 | 2.80 | 0.356 | 21.9 | 9.02 | 1800 | 1.7 |
| 83 | 2.0 | 2.80 | 0.356 | 27.8 | 13.33 | 4000 | 1.5 |
| 84 | 2.0 | 2.80 | 0.356 | 27.8 | 9.93 | 2100 | 1.5 |

^a In all experiments air is used, except in the Nos. 47-52, which have been performed with hydrogen.^b In Runs 6-71 the diameter of the column is 2.0 cm.

Notation

*(Any system of consistent units can be used.)

$$\begin{aligned}
 A_b &= \text{bubble area per unit column height} \\
 d &= \text{orifice diameter} \\
 g &= \text{acceleration due to gravity} \\
 H_b &= \text{gas holdup per unit column height} \\
 v_b &= \text{ascending velocity} \\
 F_G &= \text{gas flow rate} \\
 \gamma &= \text{surface tension} \\
 \delta &= \text{bubble diameter} \\
 \mu &= \text{viscosity of liquid} \\
 \rho &= \text{density of liquid} \\
 \Delta\rho &= \text{difference in density between liquid and gas}
 \end{aligned}$$

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Discussion

R. R. Hughes (Massachusetts Institute of Technology, Cambridge, Mass.): I think it is a valuable contribution to point out as is done in this paper the limiting condition that you cannot have more bubbles than the number that will make a chain. But I think the authors have simplified it a little bit too much in that they have attained results that seem contradictory. They claim that the velocity will drop for a bubble of the same diameter as the gas flow rate is increased—in other words, as the frequency increases. It would seem that

TABLE II—(Continued)

| No. | Height of Col. of Col. mm. | Diameter mm. | F _G cm./sec. | H _s cm./sec. | V _b cm./sec. | g mm. | Re | Ex |
|-----|-------------------------------|-----------------|----------------------------|----------------------------|----------------------------|----------|-------|------|
| 73 | 6.8 | 2.7 | 2.3 | 31.9 | 11.02 | 28.9 | 14.49 | 4200 |
| 73 | 6.8 | 2.7 | 2.9 | 28.4 | 0.957 | 27.6 | 13.32 | 3700 |
| 74 | 6.8 | 2.7 | 2.9 | 15.56 | 0.602 | 25.8 | 10.72 | 2800 |
| 75 | 6.8 | 2.6 | 2.9 | 11.11 | 0.519 | 21.6 | 9.95 | 2100 |
| 76 | 4.6 | 2.0 | 2.0 | 10.56 | 0.650 | 23.9 | 11.14 | 2700 |
| 77 | 4.6 | 2.0 | 2.0 | 0.81 | 0.368 | 18.5 | 8.28 | 1600 |
| 78 | 4.6 | 2.0 | 2.0 | 24.4 | 0.909 | 26.6 | 12.18 | 3500 |
| 79 | 2.9 | 2.6 | 2.0 | 0.11 | 0.344 | 17.8 | 8.11 | 1400 |
| 80 | 2.9 | 2.0 | 2.0 | 0.03 | 0.447 | 20.2 | 9.24 | 1900 |
| 81 | 2.9 | 2.0 | 2.0 | 12.20 | 0.530 | 22.5 | 10.25 | 2200 |
| 82 | 2.9 | 2.0 | 2.0 | 7.36 | 0.337 | 21.4 | 8.02 | 1800 |
| 83 | 1.49 | 2.0 | 2.0 | 15.83 | 0.600 | 26.4 | 10.71 | 2800 |
| 84 | 1.49 | 2.0 | 2.0 | 27.8 | 0.930 | 29.9 | 13.33 | 4000 |

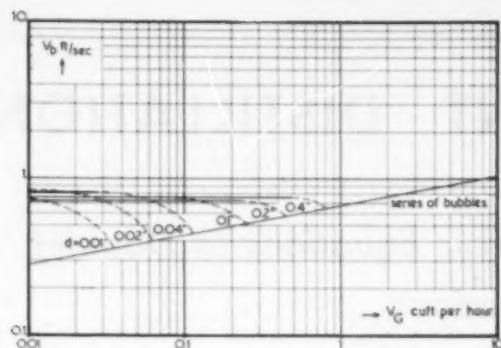


Fig. 6. V_b as a Function of V_G for Water.

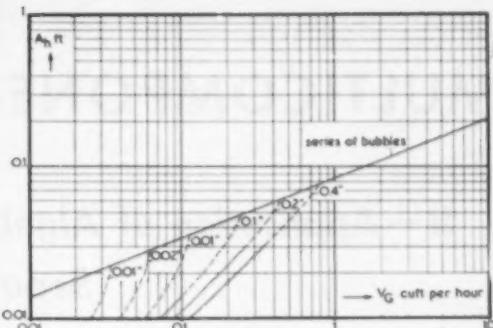


Fig. 7. $A_h R$ as a Function of V_G for Water.

TABLE 2.—(Continued)

Height of column = 51 cm. Diameter of column 5.3 cm.

| No. | d mm. | V_G cu.cm. sec. | H_s cm. | τ_s cm.sec. | δ mm. | Re | Ex |
|-----|------------|-------------------------|--------------|---------------------|-----------------|-------|-----|
| 150 | 1.2 | 7.36 | 0.347 | 21.2 | 8.34 | 17000 | 1.8 |
| 160 | 1.2 | 6.11 | 0.317 | 19.3 | 7.78 | 13000 | 2.1 |
| 161 | 1.2 | 3.89 | 0.188 | 20.7 | 5.99 | 13000 | 1.4 |
| 162 | 1.2 | 6.39 | 0.297 | 21.5 | 7.88 | 16000 | 1.6 |
| 163 | 1.2 | 10.83 | 0.515 | 21.0 | 9.92 | 21000 | 2.2 |
| 164 | 1.2 | 53.3 | 1.645 | 25.4 | 17.72 | 32000 | 1.7 |
| 165 | 1.2 | 54.1 | 1.626 | 22.0 | 15.39 | 43000 | 1.8 |
| 166 | 1.2 | 54.4 | 1.108 | 31.0 | 14.56 | 45000 | 1.5 |
| 167 | 1.2 | 24.9 | 0.911 | 27.3 | 13.18 | 36000 | 1.7 |
| 174 | 0.55 | 3.89 | 0.218 | 17.8 | 6.45 | 32000 | 2.0 |
| 175 | 0.55 | 4.72 | 0.238 | 19.8 | 6.75 | 12000 | 1.7 |
| 176 | 0.55 | 10.00 | 0.426 | 22.5 | 9.02 | 21000 | 1.6 |
| 177 | 0.55 | 6.94 | 0.317 | 21.9 | 7.78 | 17000 | 1.6 |
| 178 | 0.55 | 38.1 | 1.345 | 28.3 | 16.03 | 45000 | 2.0 |
| 179 | 0.55 | 36.1 | 1.228 | 29.4 | 15.33 | 45000 | 1.7 |
| 244 | 1.8 | 262 | 4.39 | 58.7 | 28.9 | 12700 | 0.8 |

TABLE 2.—(Continued)

Experiments with other liquids:

| | | |
|----------------------|--------------------------------|-------------------------------|
| 1. Glycerol solution | $\rho \approx 1.151$ g./cu.cm. | $\mu \approx 10.2$ centipoise |
| 2. Saponine solution | $\rho \approx 1.00$ g./cu.cm. | $\mu \approx 1.0$ centipoise |
| 3. Cyclohexane | $\gamma \approx 46.5$ dyne/cm. | |
| 4. Mineral oil | $\rho \approx 0.779$ g./cu.cm. | $\mu \approx 0.95$ centipoise |
| | $\rho \approx 0.912$ g./cu.cm. | $\mu \approx 195$ centipoise |

Height of column = 66 cm.; diameter of column = 4.7 cm.; $d = 2.3$ mm.

| No. | Liquid | V_G cu.cm. sec. | H_s cm. | τ_s sec | δ mm. | Re | Ex |
|-----|--------|-------------------------|--------------|-----------------|-----------------|------|-----|
| 20 | 1 | 16.11 | 0.622 | 25.9 | 10.70 | 310 | 1.6 |
| 21 | 1 | 5.69 | 0.318 | 17.9 | 7.79 | 160 | 2.4 |
| 22 | 1 | 8.33 | 0.394 | 21.1 | 8.68 | 210 | 1.9 |
| 23 | 1 | 13.06 | 0.576 | 22.7 | 10.41 | 270 | 2.0 |
| 24 | 1 | 27.2 | 0.945 | 27.6 | 15.71 | 420 | 1.8 |
| 25 | 1 | 19.72 | 0.786 | 26.0 | 13.27 | 350 | 1.9 |
| 26 | 1 | 16.53 | 0.697 | 23.7 | 11.54 | 310 | 2.0 |
| 33 | 2 | 17.22 | 0.629 | 27.4 | 10.96 | 3000 | 1.6 |
| 34 | 2 | 11.67 | 0.447 | 26.1 | 9.24 | 2400 | 1.8 |
| 35 | 2 | 6.67 | 0.288 | 22.3 | 7.42 | 1700 | 1.6 |
| 36 | 2 | 25.3 | 0.910 | 27.8 | 15.18 | 3700 | 1.7 |
| 37 | 2 | 19.17 | 0.758 | 25.2 | 12.03 | 3000 | 1.8 |
| 38 | 2 | 25.3 | 1.075 | 26.1 | 14.12 | 3700 | 2.1 |
| 39 | 2 | 27.8 | 1.030 | 27.0 | 14.02 | 3000 | 1.9 |
| 60 | 2 | 9.44 | 0.500 | 16.9 | 9.77 | 1900 | 2.7 |
| 61 | 2 | 11.61 | 0.561 | 24.3 | 10.35 | 2500 | 1.7 |
| 62 | 2 | 5.42 | 0.258 | 21.0 | 7.02 | 1500 | 1.6 |
| 94 | 2 | 14.72 | 0.712 | 26.7 | 11.66 | 2000 | 2.7 |
| 95 | 2 | 7.78 | 0.440 | 17.7 | 9.17 | 1300 | 2.9 |
| 96 | 2 | 30.6 | 1.165 | 23.3 | 14.93 | 3200 | 2.1 |
| 97 | 2 | 24.4 | 1.105 | 22.1 | 14.53 | 2600 | 2.9 |
| 98 | 2 | 36.3 | 1.378 | 26.0 | 16.22 | 3500 | 2.3 |
| 113 | 4 | 45.8 | 1.270 | 36.1 | 29.6 | 50 | 2.2 |
| 114 | 4 | 47.7 | 1.378 | 34.6 | 30.1 | 50 | 2.5 |

any effect of one bubble on the other would be to decrease the velocity rather than increase it. I think that is explained by the fact that they were extrapolating

their results to rather high values. Their experimental work was limited to a rather small orifice, and there may be some wall effect.

They have contributed a great deal also in explaining frequency reported by Eversole, Wagner, & Stackhouse, but I don't think they can explain Mr. Davidson's frequency of 11 bubbles/sec.

Stanley Marple, Jr. (Shell Oil Co.): We are interested in the extent of interference of one slot upon another. I wonder if any of these investigators has performed any experiments which would indicate to what extent an orifice with a single slot can be used on a bubble tray.

Written Discussion

D. W. van Krevelen and P. J. Hoftijzer: Mr. Hughes expresses his doubt whether the rising velocity may decrease when the gas rate is increased.

From experiments carried out we have found that the rising velocity of separately ascending bubbles is often greater than for series of bubbles of the same diameter. Consequently there must exist a zone of transition somewhere, in which the rising velocity decreases when the gas rate is increased.

The fact that over a certain gas rate Mr. Davidson has found a practically constant frequency fits in with the theory developed by us. The only difference is that we should expect a higher numerical value of the frequency. This deviation may be due to the very large diameter of the orifices used by Mr. Davidson. We do not know whether Mr. Davidson took precautions in order to avoid internal wetting of the orifices.

Mr. Marple asks how far different orifices may interfere upon each other. We found that interference occurs when the distance between the orifices is of the same order of magnitude as the bubble diameter. Up to now we have not succeeded in calculating results of this interference.

(Presented at Forty-first Annual Meeting, New York, N. Y.)

MULTICOMPONENT DISTILLATION

II—Application of Algebraic Equations to Doublet Separations

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Doublet separations are defined as those in which the key components are adjacent, and are the only components appearing in appreciable proportions in both products of a distilling column. Separation of the keys need not be sharp. For doublet separations the general equations derived in the first paper of this series reduce to relatively simple forms. In the present paper these forms are given, and both accurate and approximate methods for solving them shown. Methods start with the calculation, by a simple trial and error, of certain constants of the system. These constants are then used to set up a set of linear algebraic equations. The simultaneous solution of this set gives an equation relating the number of rectifying trays to the number of stripping trays. No trial-and-error method, beyond that mentioned for the first step, is involved.

THE previously derived equations (2) for the distillation of multicomponent systems, under conditions of constant volatility ratios and constant molal reflux, take relatively simple forms when only the two key components appear in appreciable proportions in both the top and bottom products of the column. The equations can then be solved readily, with a minimum of trial and error. These equations hold for any reflux, including the minimum.

The treatment to be given applies directly to columns with boiling-point liquid feeds; the modification necessary to adapt it to other types of feeds may readily be made by methods which will be shown in a subsequent paper. Both accurate and approximate methods of calculation are given; selection of the method to be used in any specific case may be made systematically.

Previous Work. The theoretical development by Underwood (5) of the basic distillation equations parallels that of the previous article in this series (2), although the nomenclature and the methods of derivation differ considerably.

Note. Part I of this series was published in *C.E.P.*, November, 1948, page 855.

ably. For convenience in comparison, a list of some corresponding symbols follows:

| <i>This Series</i> | <i>Underwood</i> |
|-------------------------|--|
| ρ | $R/(1+R)$ |
| σ | $S/(1+S)$ |
| K_{ij} | $\frac{R}{1+R} \cdot \frac{1}{\phi_j}$ |
| K_{ij} | $\frac{1+S}{S} \cdot \frac{1}{\phi_i}$ |
| a_i | k_i |
| b_j | $-\mu_j$ |
| $(1-\rho)x_{D_i}$ | $c_{i,L}$ |
| $a_i K_{ri} - \rho$ | |
| $(1-\sigma)x_{B_i}$ | $c'_{i,L}$ |
| $1 - \sigma a_i K_{ri}$ | |

Scheibel (3) has given some methods for the application of Underwood's equations, which would apply equally well to those of the present author.

Doublet Separations. The type of separation considered in this paper may be called a doublet separation. By this is

meant one in which the two keys are adjacent, and in which all components heavier than the heavy key go almost entirely into the bottom product, while all components lighter than the light key are taken off almost exclusively in the top product. In other words, essentially only the two keys are distributed; however, separation of the keys need not be sharp. Because of this restriction, coupled with the fact that the separation ratios of the two keys are to be taken as the specifications of the separation, the product compositions are known in advance except for the small, unknown amounts of undistributed components.

Basic Equations. As was shown in the previous paper, the separation ratio (sr)_i of any component *i* is given, for boiling point liquid feed, by the equation:

$$(sr)_i = \frac{Dx_{D_i}}{Bx_{B_i}} = \frac{\sum_{j=1}^c a_j K_{rj}^{-1}}{\sum_{i=1}^c b_i / K_{ri}^{M+1}}$$
$$= \frac{\sum_{j=1}^c b_j / K_{rj}^{M+1}}{\sum_{i=1}^c 1 / a_i K_{ri}^{-1}} = \frac{\sum_{j=1}^c b_j / K_{rj}^{M+1}}{\sum_{i=1}^c 1 - \frac{\rho}{a_i K_{ri}}} \quad (1)$$

where the a 's, b 's and K 's are constants of the system defined by the equations

$$\sum_{i=1}^c \frac{x_{D_i}}{1 - \frac{\rho}{a_i K_{ri}}} = \frac{1}{1 - \rho}$$

or

$$\sum_{i=1}^c \frac{x_{B_i}}{a_i \left(K_{ri} - \frac{\rho}{a_i} \right)} = \frac{1}{1-\rho} \quad (2)$$

$$\sum_{i=1}^c \frac{x_{B_i}}{1 - \frac{1}{\sigma a_i K_{ri}}} = \frac{\sigma}{1-\sigma}$$

or

$$\sum_{i=1}^c \frac{x_{B_i}}{1 - \sigma a_i K_{ri}} = \frac{1}{1-\sigma} \quad (3)$$

$$\frac{K_{ri}}{a_i} = (1-\rho) \cdot \sum_{i=1}^c \frac{x_{B_i}}{a_i \left(1 - \frac{\rho}{a_i K_{ri}} \right)^2} \quad (4)$$

$$\frac{K_{ri}}{b_j} = \frac{1-\sigma}{\sigma} \cdot \sum_{i=1}^c \frac{x_{B_i}}{\sigma a_i \left(\frac{1}{\sigma a_i K_{ri}} - 1 \right)^2} \quad (5)$$

Two forms of Equations (2) and (3) are equivalent. The subscript i is assigned so that $a_1 < a_2 < \dots < a_c$, where c is the number of components in the feed to the column. The subscript j may have any value from 1 to c ; the K 's and K_r 's are thus the c roots of Equations (2) and (3), respectively. The assignment of j is such that

$$a_{j-1} < \frac{\rho}{K_{rj}} < a_j$$

and

$$a_j < \frac{1}{\sigma K_{sj}} < a_{j+1}$$

also

$$\rho a_1 < \frac{\rho}{K_{r1}} < a_1$$

and

$$a_c < \frac{1}{\sigma K_{sc}} < \frac{a_c}{\sigma}$$

it follows that $K_{rc} < K_{re-1} < \dots < K_{r2} < K_{r1}$ and $K_{sc} < K_{se-1} < \dots < K_{s2} < K_{s1}$. Each component, i , may be regarded as having an effective volatility equal to ρ/K_{ri} in the rectifying section and $1/\sigma K_{si}$ in the stripping section.

Let the subscript H be used to denote a component having a value of a less than that of the heavy key, and the subscript L to denote one with a greater than that of the light key. There may be any number of H 's and L 's; these components may collectively be called the outside components to distinguish them from the keys.

It can be seen from an inspection of Equations (2) and (3) that when the separation ratios of the keys are specified, the product compositions are sufficiently well defined to fix within very

narrow limits the values of all K_{rl} 's, K_{rh} and K_{sh} , all K_{ri} 's, K_{si} and K_{sl} . In calculating these K 's all x_{B_H} 's and x_{B_L} 's can be set equal to zero. Subsequent calculation of these x_B 's and x_R 's is not invalidated.

Any component H is present in the top product at low concentration; therefore K_{rh} is close to ρ/a_H , as shown previously. Equation (2) shows that

$$\frac{x_{B_H}}{1 - \frac{\rho}{a_H K_{rh}}} = u_H \quad (6)$$

where

$$u_H = \frac{\rho}{1-\rho} - \sum_{i \neq H} \frac{x_{B_i}}{a_i - 1} \quad (7)$$

Since a_H and U_L are finite and of appreciable magnitude, a_H and b_L are very small but

$$a_H / \left(1 - \frac{\rho}{a_H K_{rh}} \right)$$

and

$$b_L / \left(\frac{1}{\sigma a_L K_{sl}} - 1 \right)$$

are not.

Now let the following three new symbols be defined:

$$s_H = \frac{a_H}{a_k} \left(\frac{K_{rh}}{K_{rk}} \right)^N, \quad S_j = \frac{b_j}{b_k} \left(\frac{K_{sl}}{K_{sr}} \right)^{M+1} \quad (14)$$

defines u_H . Likewise, any component L is present at very low concentration in the bottom product, B ; Equation (3) shows that

$$\frac{x_{B_L}}{1 - \frac{1}{\sigma a_L K_{sl}}} = U_L \quad (8)$$

where

$$U_L = \frac{\sigma}{1-\sigma} - \sum_{i \neq L} \frac{x_{B_i}}{a_i - 1} \quad (9)$$

defines U_L . For any component H , dilute in the top product, a_H is found by setting $j = H$ in Equation (4) and noting that on the right-hand side the term with $i = H$ is much larger than the others. This gives

$$a_H = \frac{\rho}{1-\rho} \cdot \frac{x_{B_H}}{u_H^2} \quad (10)$$

Further,

$$\frac{a_H}{1 - \frac{\rho}{a_H K_{rh}}} = \frac{\rho}{1-\rho} \cdot \frac{1}{u_H} \quad (11)$$

Similarly, for any component L , dilute in the bottom product,

$$b_L = \frac{\sigma}{1-\sigma} \cdot \frac{x_{B_L}}{U_L^2} \quad (12)$$

and

$$\frac{b_L}{1 - \frac{1}{\sigma a_L K_{sl}}} = \frac{\sigma}{1-\sigma} \cdot \frac{1}{U_L} \quad (13)$$

$$(sr)_i = Z \cdot \frac{\frac{S_h}{1 - \frac{1}{\sigma a_i K_{rh}}} + \frac{1}{1 - \frac{1}{\sigma a_i K_{sl}}} + \sum_{L \neq i} \frac{S_L}{a_L - 1}}{\sum_{H \neq i} \frac{s_H}{1 - \frac{a_H}{a_i}} + \frac{1}{1 - \frac{\rho}{a_i K_{rh}}} + \frac{1}{1 - \frac{\rho}{a_i K_{sl}}}} \quad (16)$$

for the two keys (i.e., $i = h$ or l), and to

$$s_H = Z \cdot \frac{Bx_{BH}}{Dx_{BL}} \left(\frac{S_h}{\frac{1}{\sigma a_H K_{sh}} - 1} + \frac{1}{\frac{1}{\sigma a_H K_{sh}} - 1} + \sum_L \frac{S_L}{\frac{a_H}{a_L} - 1} \right) \quad (17)$$

$$S_L = \frac{1}{Z} \cdot \frac{Dx_{BL}}{Bx_{BH}} \left(\sum_H \frac{s_H}{1 - \frac{a_H}{a_L}} + \frac{1}{1 - \frac{\rho}{a_L K_{sh}}} + \frac{s_l}{1 - \frac{\rho}{a_L K_{sl}}} \right) \quad (18)$$

for all the H and L components, respectively.

Nature of Solutions of Equations. In Equations (16), (17) and (18) everything is known or immediately calculable except the s_H 's, S_L 's, x_l , S_h and Z . Including Equation (15), which defines Z , there are $c+1$ equations. Only c of these are independent, as previously pointed out (2). There are $c+1$ unknowns, so that there is one independent variable. In the following it will be assumed that this variable is s_l ; the main object of the calculations will be to determine S_h as a function of s_l . From this relationship the stripping tray requirement, M , corresponding to any arbitrary number, N , of rectifying trays can be calculated directly. In order to obtain this relation between S_h and s_l it is necessary to calculate first the values of the s_H 's and S_L 's and to substitute these in Equation (16). In doing so it is convenient to regard Z as a parameter. If this is done Equations (17) and (18) form a set of simultaneous linear equations which can be solved directly for the s_H 's and S_L 's in terms of Z , s_l and S_h . Results are always of the form

$$s_H = k_1 + k_2 s_l + Z(k_3 S_h + k_4) \quad (19)$$

$$S_L = \frac{k_5 + k_6 s_l}{Z} + k_7 S_h + k_8 \quad (20)$$

where the k 's are constants for the given system, depending on the a 's, product compositions, and the reflux ratio. Next substitute relations (19) and (20) in any of the three equations (15) and (16), and solve for Z . In each case Z is involved linearly, and the solution is of the form

$$Z = \frac{k_9 + k_{10} s_l}{k_{11} + S_h} \quad (21)$$

where the k 's are constants of the system. Three such equations are obtained, of which only two are independent, for the reason just mentioned. Next, eliminate Z by equating any two of the three Equations (21). The result is of the form

$$S_h = -k_{12} + \frac{k_{13}}{k_{14} + s_l} \quad (22)$$

volving the s_H 's and S_L 's in Equations (16), (17), and (18) may be negligible, while under others they may be of importance.

At infinite reflux ratio, $k_{12} = 1$ and $k_{13} = k_{14} = 0$. At minimum reflux, $k_{12} \cdot k_{14} = k_{13}$. For intermediate refluxes, if $N = \infty$, M is given by

$$S_h = \frac{k_{13}}{k_{14}} - k_{12}$$

(which is usually positive); if $M = \infty$,

$$\frac{b_L}{b_H} \left(\frac{K_{sh}}{K_{sl}} \right)^{M+1} = -k_{12} + \frac{k_{13}}{k_{14} + \frac{a_L}{a_H} \left(\frac{K_{sl}}{K_{sh}} \right)^N} \quad (23)$$

From this equation the M corresponding to any N may be calculated. It may be noted that

$$1 > \frac{K_{sl}}{K_{sh}} > \frac{a_L}{a_{L-1}}$$

and

$$1 > \frac{K_{sl}}{K_{sh}} > \frac{a_L - 1}{a_L}$$

Nearly always, both K_{sl}/K_{sh} and K_{sl}/K_{sh} are between unity and a_L/a_L .

Finally the x_{BH} 's and x_{BL} 's are computed as follows:

$$x_{BH} = \frac{1 - \rho}{\rho} \cdot a_L a_H^2 \cdot s_H \left(\frac{a_H K_{sh}}{\rho} \right)^N$$

$$x_{BL} = \frac{1 - \sigma}{\sigma} b_L U_L^2 S_L / (\sigma a_L K_{sl})^{M+1}$$

The only trial and error involved in the entire calculation are those in the initial determination of K_{sh} , K_{sl} , K_{sh} and K_{sl} . It is necessary, of course, for the validity of Equations (16), (17), and (18) that (for all N and M values considered) the separations of the non-key components be sharp.

Properties of Equations (22) and (23). Under all circumstances, $s_h = 1$, $S_L = 1$, by definition. It can readily be shown that if the reflux ratio is infinite ($\rho = 1$), each s_H and S_L is zero, while $s_h S_h = 1$. At minimum reflux, where N and M are both infinite, s_H and S_L are finite while $s_l = S_h = 0$. Values of the s 's and S 's for a finite reflux ratio are intermediate between those for infinite and minimum reflux ratios. Therefore the relative importance of the outside components in determining the plate requirements depends upon the reflux ratio, increasing as the latter decreases. Also, as may be seen from Equations (17) and (18), the s_H 's and S_L 's depend upon the magnitude of the x_{BH} 's and x_{BL} 's. It is therefore apparent that under some circumstances the terms in-

N is given by

$$s_l = \frac{k_{14}}{k_{12}} \left(\frac{k_{13}}{k_{14}} - k_{12} \right)$$

In general, a plot of S_h vs. s_l is hyperbolic, as is (qualitatively) M vs. N . As expected, the plot of total plates ($N + M$) vs. N shows a minimum which can if desired be calculated from the k 's, as shown below.

Methods of Application. The simplest method of applying Equations (16), (17), and (18) would be to make the well-known assumption that the H components do not affect the rectifying section and the L components do not affect the stripping section. This amounts to setting all s_H 's and S_L 's equal to zero, and may be called the zero'th order approximation. This is not always allowable, however, since as already pointed out the numbers neglected may be of considerable magnitude; this is particularly true near minimum reflux or when the nonkey components form a large proportion of the feed.

The method which will be called the first approximation neglects the summation terms in Equations (17) and (18), but includes them in Equations (16); the accuracy of this method is considerably better than that of the zero'th approximation.

The complete method uses all of Equations (16), (17), and (18) exactly as written, and is accurate within the limitations of the assumptions underlying the equations.

Various combinations of these methods are also possible. For instance if the zero'th order calculation shows the s_H 's to be small but the S_L 's to be of appreciable magnitude, the former may be neglected but the latter included in the first-order calculations.

Zero'th Approximation. Relation between S_h and s_l is obtained by dividing

Equation (16) without the summation terms, written for the heavy key ($i=h$), by the same equation written for the light key ($i=l$) and solving for S_h . The result is of the form of Equation (22). Distributions of the nonkey components can then be calculated from Equations (24); for this purpose s_H and S_L are calculated from Equations (17) and (18), omitting the summation terms.

First Approximation. In applying the first approximation the initial step is to calculate each s_H/Z and ZS_L from Equations (17) and (18), neglecting the summation terms in each case. Then substitute in Equation (15) and solve for Z , remembering that all S_H 's and s_L 's are zero. Thus,

$$Z(1 + S_b) + \sum_L ZS_L = 1 + s_l + Z \cdot \sum_H s_{H/p}$$

so that

$$Z = \frac{1 + s_l - \sum_L ZS_L}{1 + S_b - \sum_H s_{H/p}} \quad (25)$$

For the keys,

$$(sr)_l = \frac{Z \left(\frac{S_h}{\frac{1}{\alpha_i K_{sh}} - 1} + \frac{1}{\frac{1}{\alpha_i K_{sl}} - 1} \right) + \sum_L \frac{ZS_L}{\frac{\alpha_L}{\alpha_i} - 1}}{Z \cdot \sum_H \frac{s_{H/p}}{1 - \frac{\alpha_H}{\alpha_i}} + \frac{1}{1 - \frac{\rho}{\alpha_i K_{sh}}} + \frac{s_l}{1 - \frac{\rho}{\alpha_i K_{sl}}}} \quad (26)$$

TABLE I.—SPECIFICATIONS AND CONSTANTS OF SYSTEM FOR FOUR-COMPONENT EXAMPLE

| Com- ponent No. | Boiling Point Liquid Feed | | | | | |
|-----------------------|--|-----------------------------------|--------|-----------|-----------|-----------|
| | Mole Frac- tion in Feed, x_F | Separ- ation Ratio, (sr) | Dx_D | Bx_B | σ | δ |
| 1 (=H) | 0.25 | 0.100 | — | 0* | 0.100* | 0.297876 |
| 2 (=h) | 0.50 | 0.225 | 0.050 | 0.016714 | 0.214286 | 0.0361285 |
| 3 (=l) | 1.00 | 0.450 | 20.005 | 0.428576 | 0.0214238 | 0.645164 |
| 4 (=L) | 2.00 | 0.525 | — | 0.225000* | 0* | 0.338708* |
| | | | | | | 0* |
| | | | | | | 1.000 |

* Assumed for calculation of K 's, a 's and b 's of keys only.

$D/B = 1.97876$

$$\text{Reflux ratio (internal)} = 5.1; \frac{\sigma}{1-\sigma} = 5$$

$$\sigma = 0.873333; \frac{\sigma}{1-\sigma} = \frac{D/B}{1-\sigma} = 11.87257; \sigma = 0.922315$$

$$K_C = 1.67300, K_B = 0.94603, K_L = K_H = 0.565469$$

$$1/K_C = 0.486228, 1/K_B = 0.927559, K_L/K_H = 0.524186$$

$$\mu/K_C = 0.498107, \mu/K_B = 0.860874$$

$$1/\mu K_C = 0.527182, 1/\mu K_B = 1.005716$$

$$a_1 \approx 0.0044548, a_2 \approx 0.12324, a_3 \approx 27.663, a_4 \approx 27.663 \times (0.565469)^{1/2}$$

$$b_1 = 0.051986, b_2 = 0.0061397, b_3 = 8.6074, b_4 = 8.6074 \times (0.524186)^{1/2}$$

Calculation of s_H, F_L :

| Component | $x_H \left(\frac{a}{a_i} - 1 \right)$ | $x_H \left(\frac{a}{a_i} - 1 \right)$ |
|-----------|--|--|
| 1 | 0 | 0.0425537 |
| 2 | 0.0161285 | 0.2127692 |
| 3 | 0.2150547 | 0.0038164 |
| 4 | 0.0483968 | 0 |
| | 0.2795700 | 0.3191393 |

$$n_1 = 5 = 0.2795700 = 4.720430; F_L = 11.87257 - 0.31914 = 11.55343$$

where $i = h$ or l . Equation (26), for either key, is linear in Z and may be solved directly to give an expression of the form of Equation (21). Including Equation (25) there are therefore three equations for Z . By eliminating Z between any two of these Equation (22) is obtained. Since there are three pairs, there are also three equations of the form of (22). All should be identical if the calculations are correct and the approximations are adequate.

Distributions of the outside components are calculated just as in the zero'th approximation.

Complete Method. If it is necessary to use the complete method, the procedure outlined under "Nature of Solutions

of the Equations" should be followed. The simultaneous solution of Equations (17) (one for each H) and (18) (one for each L) may be done in any manner desired, as for instance by means of determinants or even by means of a mass spectrometer calculating device. Results of the form of Equations (19) and (20) are obtained; then from Equations (15) and (16) three equations for Z , of the form of Equation (21), are derived. Eliminate Z between any two of the three, giving three Equations (22), all of which should be identical. Then proceed as in the zero'th approximation.

Recommended Procedure. Calculational methods proposed are of advantage particularly if a thorough investigation of the effects of operating conditions on the plate requirements for a given separation is to be made. The procedure recommended is as follows:

1. Calculate minimum plate requirement, corresponding to infinite reflux ratio, by Fenske's method.
2. Calculate minimum reflux ratio by Underwood's method (4).
3. Pick a suitable reflux ratio, say 25% greater than minimum, for further calculations.
4. Make a zero'th order calculation. Then check the magnitudes of the summation (Σ) terms in Equations (17) and (18) on the s_H 's, the S_L 's and Equation (16).
5. If (as is often the case) the check in Item 4 shows the zero'th approximation to be of insufficient accuracy, carry out a first-order approximation. Check adequacy of approximations.
6. If terms neglected in the first-order approximation are not negligible, carry out the calculation by the complete method.

Illustrative Calculations. The procedure outlined will be illustrated for a simple four-component example. Specifications and the primary constants of the system are shown in Table I. A molal reflux ratio of 5:1 is chosen. The K 's are calculated by trial and error from Equations (2) and (3); using these values the a 's and b 's are computed from Equations (4) and (5).

Infinite Reflux Ratio Calculation. If

$$\rho = \sigma = 1,$$

$$(sr)_l \left(\frac{a_h}{a_l} - 1 \right)^{N+M+1} = 1$$

or

$$N + M + 1 = \frac{\log ((sr)_l / (sr)_h)}{\log (a_l / a_h)} \quad (27)$$

Here,

$$N + M + 1 = \log \frac{20.005}{0.050} / \log 2.00 \\ = 8.6442$$

This is the minimum total number of theoretical plates for the given separation of the keys.

Although x_1 , x_3 and Z are not needed for this case, it is of interest that, depending on the feed plate location, these quantities may vary between the following limits:

Z and x_1 ; x_{D1}/x_{B1} and x_{B1}/x_{B2} .

i.e., 40.00 and 0.09998

S_3 ; $a_3 x_{B3}/a_1 x_{B1}$ and x_{D3}/x_{B3} .

i.e., 5.001 and 0.02500

Minimum Reflux Ratio Calculation.

Minimum reflux is determined by the equations (5)

$$\sum_{j=1}^e \frac{x_{Fj}}{1 - \frac{\theta}{a_j}} = 1 - q \quad (28)$$

$$\sum_{j=t}^e \frac{x_{Dj}}{1 - \frac{\theta}{a_j}} = \frac{1}{1 - \rho} \quad (29)$$

Here, q is the total heat required to vaporize one mole of feed, divided by the molal latent heat of vaporization. In the present case, the feed is liquid at its boiling point and $q = 1$. θ is the root of Equation (28) which is between a_3 and a_4 . When this equation is satisfied,

$$\rho/K_{rl} = \frac{1}{\sigma K_{sh}} = \theta$$

In the present case it is found by trial that $\theta = 0.58478$. The reflux to which this corresponds is obtained by substituting $\theta = 0.58478$ in Equation (29); ρ is thus found to be 0.48383, corresponding to which σ is 0.79311. The corresponding reflux ratio, which is equal to $\rho/1 - \rho$, is 0.93735.

Separations of the nonkey components are complete at minimum reflux.

Magnitudes of Constants of System at Minimum Reflux. Although values of all the constants of the system at minimum reflux are not required for the calculations reported here, they are significant in that they are limits beyond which the corresponding quantities for finite refluxes cannot go. By carrying out calculations similar to those for the complete method (but with s_3 and S_2 set equal to zero), the following values for the example system at minimum reflux are found:

$$K_{r1} = 1.93530 \quad \rho/K_{r1} = 0.25000$$

$$K_{r2} = 1.02784 \quad \rho/K_{r2} = 0.470720$$

$$K_{r3} = 0.826367 \quad \rho/K_{r3} = 0.584778$$

$$K_{r4} = 0.275268 \quad \rho/K_{r4} = 1.75765 \\ K_{s1} = 4.77379 \quad 1/\sigma K_{s1} = 0.264121 \\ K_{s2} = 2.15612 \quad 1/\sigma K_{s2} = 0.584778 \\ K_{s3} = 1.23562 \quad 1/\sigma K_{s3} = 1.020486 \\ K_{s4} = 0.630429 \quad 1/\sigma K_{s4} = 2.00000$$

therefore not satisfactory for refluxes near the minimum, for the particular system in question.

Zero'th Order Calculation for 5:1 Reflux Ratio.

The equation used is

$$Z = \frac{\frac{1}{1 - \frac{\rho}{a_2 K_{r2}}} + \frac{x_3}{1 - \frac{\rho}{a_2 K_{r3}}}}{\frac{1}{S_2} + \frac{1}{\frac{1}{\sigma a_2 K_{s2}} - 1}} = \frac{\frac{1}{1 - \frac{\rho}{a_3 K_{r2}}} + \frac{x_3}{1 - \frac{\rho}{a_3 K_{r3}}}}{\frac{1}{S_2} + \frac{1}{\frac{1}{\sigma a_3 K_{s2}} - 1}} \quad (30)$$

Substitution of numerical values in the two right-hand members of this equation gives

$$\frac{13.2066 - 0.065638 s_3}{0.988697 + 18.3932 S_2} = \frac{39.8591 + 167.805 s_3}{174.948 - 2.11498 S_2} \quad (31)$$

Solving for S_2 ,

$$S_2 = -0.05748 + \frac{0.7500}{0.2466 + s_3} \quad (32)$$

This is the equivalent of Equation (22). Substituting for s_3 and S_2 , and simplifying, Equation (31) reduces to

$$(0.5242)^{M+1} = -0.006678 + \frac{0.003150}{0.008914 + (0.5655)^N} \quad (33)$$

A first-order calculation at minimum reflux gives $s_1 = 0.044586$, $S_4 = 0.31366$, $Z = 0.79518$. A zero-order approximation assumes that $s_1 = S_4 = 0$ and $Z = 1$.

$$s_1 = Z \frac{Bx_{B1}}{Ds_1} \left(\frac{S_2}{\frac{1}{\sigma a_1 K_{s2}} - 1} + \frac{1}{\frac{1}{\sigma a_3 K_{s3}} - 1} \right) \quad (34)$$

$$S_4 = \frac{1}{Z} \frac{Dx_{B4}}{BU_4} \left(\frac{1}{1 - \frac{\rho}{a_4 K_{r2}}} + \frac{s_3}{1 - \frac{\rho}{a_4 K_{r3}}} \right) \quad (35)$$

Substituting numerical values,

$$\frac{s_1}{Z} = 0.0105496 + 0.0287626 S_2$$

$$Z S_4 = 0.0772505 + 0.103673 s_3$$

Also,

$$Z = \frac{1 + s_3 - Z S_4}{1 + S_2 - s_1 / Z} \\ = \frac{0.9227495 + 0.896327 s_3}{0.9894504 + 0.9712374 S_2} \quad (36)$$

From Equation (26)

$$Z = \frac{(sr)_1 \left(\frac{1}{1 - \frac{\rho}{a_2 K_{r2}}} + \frac{x_3}{1 - \frac{\rho}{a_2 K_{r3}}} \right) - \frac{Z S_4}{\frac{a_4}{a_1} - 1}}{\frac{1}{S_2} + \frac{1}{\frac{1}{\sigma a_4 K_{s3}} - 1} - (sr)_1 \frac{s_1 / Z}{1 - \frac{a_1}{a_4}}} \quad (37)$$

Substituting $i = 2$ or 3 and equating the right-hand sides, the analogues of Equations (30) and (31) are obtained. Numerical values of s_1/Z and ZS_4 obtained above are used. Note that except for the ZS_4 and s_1/Z terms, the quantities appearing in Equation (37) are identical with those in Equations (30) and (31); in other words, computations involved in the zero'th approximation are, up to this point, usable in the first approximation. A similar statement is true for the transition from the first approximation to the complete method.

Carrying out the indicated substitutions it is found that

$$Z = \frac{13.1808 - 0.100196s_3}{0.987642 + 18.3902S_2}$$

Solving for S_2 ,

$$S_2 = -0.05938 + \frac{0.7486}{0.2496 + s_3} \quad (39)$$

This is the analogue of Equations (22) and (32). A similar elimination of Z between Equation (36) and the two right-hand members of Equation (38), in turn, gives

$$S_2 = -0.05937 + \frac{0.7465}{0.2514 + s_3} \quad (40)$$

and

$$S_2 = -0.05665 + \frac{0.7503}{0.2496 + s_3} \quad (41)$$

respectively. Equations (39), (40) and (41) should be identical if the first-order approximation is adequate. In the present case it is seen to be reasonably good. From any one of these equations, or their average, an equation similar to Equation (33) may be obtained.

Complete Calculation for 5:1 Reflux Ratio. The complete method neglects nothing in Equations (16), (17) and (18). In the present case the equations for s_1 and S_4 are:

$$\frac{s_1}{Z} = 0.031890 \left(\frac{S_2}{1.10873} + \frac{1}{3.02286} + \frac{S_4}{Z} \right) \quad (42)$$

$$ZS_4 = 0.058011 \left(\frac{8}{Z} s_1 + \frac{1}{0.75095} + \frac{s_3}{0.55956} \right) \quad (43)$$

Solving simultaneously,

$$\frac{s_1}{Z} = \frac{0.00035204 + 0.00047245s_3}{Z} + 0.028771S_2 + 0.010553 \quad (44)$$

$$ZS_4 = 0.077274 + 0.103704s_3 + Z(0.0019075S_2 + 0.0006996) \quad (45)$$

The definition of Z is given by $Z(S_2 + 1 + S_4) = s_1 + 1 + s_3$. Substituting

Equations (44) and (45) in the definition equation and solving for Z it is found that

$$Z = \frac{0.94856 + 0.92152s_3}{S_2 + 1.01748} \quad (46)$$

From Equation (16) with $i = 2$,

$$(sr)_2 = 0.050 = \frac{Z(18.3946S_3 + 0.98870) + ZS_4/3}{2s_1 + 264.158 - 1.31277s_3} \quad (47)$$

Substituting Equations (44) and (45) and solving,

$$= \frac{39.7818 + 167.701s_3}{174.666 - 2.88217S_2} \quad (38)$$

$$Z = \frac{13.1822 - 0.100159s_3}{18.3923S_2 + 0.98788} \quad (48)$$

Similarly, it is found from Equation (16) with $i = 3$, and with Equations (44) and (45) substituted, that

$$Z = \frac{39.7912 + 167.840s_3}{174.680 - 2.88048S_2} \quad (49)$$

Elimination of Z gives the following results:

Between Equations (46) and (48)

$$S_2 = -0.05937 + \frac{0.7465}{0.2501 + s_3} \quad (50)$$

Between Equations (48) and (49)

$$S_2 = -0.05938 + \frac{0.7480}{0.2494 + s_3} \quad (51)$$

Between Equations (46) and (49)

$$S_2 = -0.05749 + \frac{0.7487}{0.2494 + s_3} \quad (52)$$

All these equations for S_2 should agree, except for cumulative numerical errors. The first two check satisfactorily; the

last involves differences between large numbers, and is the least reliable. Averaging the first two, S_2 is taken to be

$$S_2 = -0.05938 + \frac{0.7473}{0.2497 + s_3} \quad (53)$$

Substituting for s_3 and S_2 from Table 1,

$$(0.5242)^{M+1} = -0.006899 + \frac{0.003139}{0.009026 + (0.5655)^N} \quad (54)$$

Solving for M ,

$$M = \frac{\log(\text{right-hand side}) - 1}{\log(0.5242)}$$

Table 2 shows the values of the plate numbers calculated from this formula. Values of the other variables appearing in the equations are also shown for comparison. The mole fractions of the outside components, x_{D1} and x_{B4} , were calculated by means of Equations (24). A plot of total plates required, $N + M$, vs. the number of rectifying plates, N , is shown in Figure 1. The variation of 100 x_{D1} (mole per cent of heaviest component in top product) and 100 x_{B4} (mole per cent of lightest component in bottom product) with N is shown in Figure 2.

The basic formulas Equations (16), (17), (18) used in this paper are not valid unless both x_{D1} and x_{B4} are very small. Calculations show that this requirement is met for the example system except, perhaps, when the number of plates in one or the other section of the column is large relative to the number required for minimum total plates.

Figure 1 shows that, in the neighborhood of the optimum feed plate location the total plate requirement is insensitive to the feed plate location. On the other hand, the relative sensitivity of the separations of the outside components (numbers 1 and 4) is much greater, their variation being roughly exponential in this neighborhood. If the distributions of the outside components are important, the optimum feed plate location may not be the most desirable.

Optimum Feed Plate Location. Differentiation of Equation (22) shows that with the optimum feed plate location

$$\frac{S_3}{k_{13}} + 1 = \frac{-r_a + (2 - r_a)\sqrt{1 - \frac{(1 - r_a)k_{15}}{\left(1 - \frac{r_a}{2}\right)^2}}}{2(1 - r_a)(1 - k_{15})} \quad (55)$$

$$\frac{s_1}{k_{14}} + 1 = \frac{r_a + (2 - r_a)\sqrt{1 - \frac{(1 - r_a)k_{15}}{\left(1 - \frac{r_a}{2}\right)^2}}}{2(1 - k_{15})} \quad (56)$$

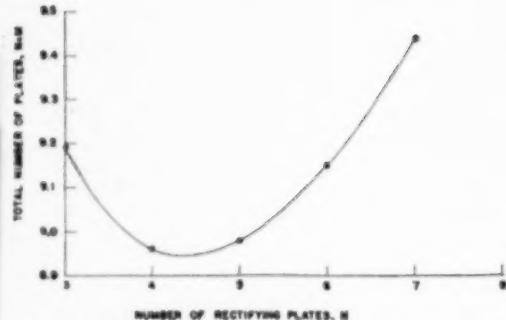


Fig. 1. Effect of Changing Feed Plate Location on Total Plate Requirement.
4-Component System, 5:1 Reflux Ratio.

where

$$r_o = 1 - \frac{\log \left(\frac{K_{13}}{K_{15}} \right)}{\log \left(\frac{K_{13}}{K_{15}} \right)}$$

$$k_{15} = 1 - \frac{k_{12} k_{14}}{k_{13}}$$

It follows, from this, that

$$\frac{S_{13} s_1}{k_{13}} = \frac{2 \left(1 - \frac{r_o}{2} \right)^2}{1 - r_o} \left(1 - \sqrt{1 - \left(1 - \frac{r_o}{2} \right)^2 k_{15}} \right) - k_{15} \quad (57)$$

If the reflux ratio is infinite, $r_o = 0$, $k_{13} = 1$ and $k_{15} = 1$. Hence $S_{13} s_1 = 1$, as expected. At minimum reflux, $k_{15} = 0$, $k_{13} = 0$. Hence $S_{13} s_1 = 0$. Near minimum reflux, k_{15} is small, while

$$\left(1 - \frac{r_o}{2} \right)^2$$

is usually not far from unity. Expansion of Equation (57) shows that under these circumstances

$$\frac{S_{13} s_1}{k_{13}} = \frac{k_{13}}{4} + \frac{(1 - r_o)^2}{\left(1 - \frac{r_o}{2} \right)^2} + k_{15}^2 + \text{higher order terms.} \quad (58)$$

This emphasizes the fact that the accuracy of a computation of $S_{13} s_1$ near minimum reflux depends upon the relative accuracy of determination of the difference quantity, k_{15} .

TABLE 2—CALCULATED VALUES OF VARIABLES FOR DISTILLATION OF EXAMPLE FOUR COMPONENT SYSTEM

| | N | M | $N+M$ | s_1 | m | S_1 | S_k | Z | $100x_{D1}$ | $100x_{A1}$ |
|---------|-------|--------|--------|---------|---------|---------|--------|--------|-------------|-------------|
| 1.4163 | — | — | — | 0.1339 | 12.337 | 0 | 0.1128 | 12.106 | 0.1001 | 0 |
| 2 | 8.188 | 10.188 | 18.376 | 0.1026 | 8.846 | 0.02278 | 0.1144 | 8.748 | 0.05130 | 0.001404 |
| 3 | 6.188 | 9.188 | 15.376 | 0.0808 | 5.003 | 0.08292 | 0.1189 | 5.052 | 0.01709 | 0.005767 |
| 4 | 4.959 | 8.959 | 13.918 | 0.04856 | 2.829 | 0.1834 | 0.1262 | 2.961 | 0.006117 | 0.01426 |
| *4.8546 | 4.591 | 8.946 | 13.537 | 0.04390 | 2.311 | 0.2225 | 0.1298 | 2.462 | 0.004331 | 0.01888 |
| 5 | 3.982 | 8.982 | 12.964 | 0.03752 | 1.600 | 0.3447 | 0.1381 | 1.779 | 0.002372 | 0.03052 |
| 6 | 3.155 | 9.155 | 12.310 | 0.03128 | 0.9047 | 0.5881 | 0.1560 | 1.110 | 0.0009925 | 0.06087 |
| 7 | 2.458 | 9.458 | 11.916 | 0.02774 | 0.5116 | 0.9224 | 0.1805 | 0.7320 | 0.0004419 | 0.1138 |
| 8 | 1.894 | 9.894 | 11.788 | 0.02575 | 0.2893 | 1.327 | 0.2102 | 0.5182 | 0.0002058 | 0.1952 |
| 9 | 1.467 | 10.467 | 11.934 | 0.02462 | 0.1636 | 1.749 | 0.2412 | 0.3974 | 0.0000877 | 0.3004 |
| 10 | 1.166 | 11.166 | 12.332 | 0.02398 | 0.09252 | 2.125 | 0.2888 | 0.3290 | 0.00004829 | 0.4117 |
| 11 | 0.969 | 12.969 | 13.938 | 0.02315 | 0 | 2.934 | 0.3282 | 0.2400 | 0 | 0.7090 |

* Feed plate location "optimum," i.e., minimum total plates required.

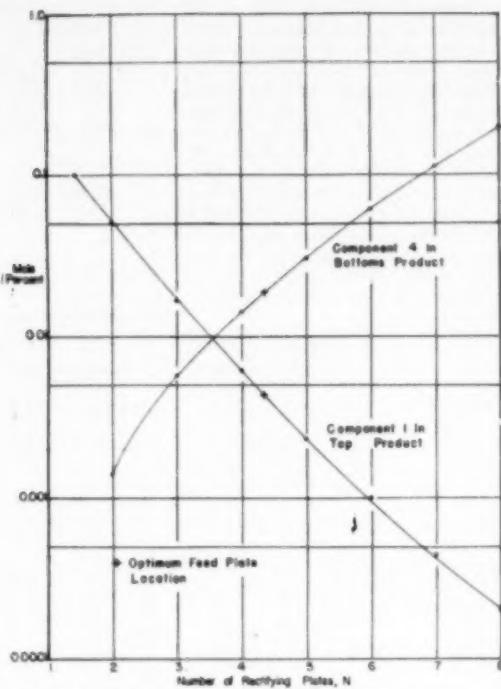


Fig. 2. Mole Per Cents of Outside Components in Products.
4-Component System, 5:1 Reflux Ratio.

As the reflux ratio increases from the minimum to infinity, the product $S_{k_1}x_1$ (from which the number of plates can be determined) rises from about $k_{12}k_{13}^2/4$ to $k_{12}k_{13}^2/1$. On the other hand, $4 S_{k_1}x_1/k_{12}(1+k_{13})^2k_{13}^2$ rises from

$$\frac{1-r_0}{\left(1-\frac{r_0}{2}\right)^2}$$

(a little less than unity), to unity. For the example system, $4 S_{k_1}x_1/k_{12}$ is 0.8072 near minimum reflux, 0.9804 at 5:1 reflux ratio, and 1.0000 at infinite reflux ratio. The possibility of semiempirical correlations is suggested.

Accurate Solution of Example Problem. A solution of the example problem for a reflux ratio of 5:1, using Equation (1) without approximations, was carried out by trial and error, and the results reported in the first paper of this series (2); the feed plate location was optimum. Agreement with the results of the present paper was good. It is believed that because the amount of trial and error in the methods described here is much less than in the procedure using Equation (1) directly, the results reported in Table 2 are of a reliability equal or superior to those reported in the previous paper.

Comparison of Complete and Approximate Methods. For the example system with a 5:1 reflux ratio, the agreement between the complete method and the first-order approximation is excellent, while that between the complete method and the zeroth order approximation is fairly good. Near minimum reflux the first-order approximation is fairly good, but the zeroth order approximation is unsatisfactory. This trend may be expected to be followed generally, but the refluxes below which the approximate methods become unsatisfactory will depend upon the system being fractionated and the separation ratio specifications. It is an advantage of the proposed method that the values of the terms neglected in Equations (17) and (18) when using one of the approximate methods can be estimated satisfactorily without carrying through the complete method.

Acknowledgment

This research was supported in part by the Texas Engineering Experiment Station; the aid given is gratefully acknowledged.

Notation

a_j = rectifying section coefficient appearing in Eq. (1); defined by Eq. (4). $j = 1$ to c

b_j = stripping section coefficient appearing in Eq. (1); defined by Eq. (5). $j = 1$ to c

B = moles of bottom product per mole of feed

D = moles of top product per mole of feed

k = constant of system, as in Eqs. (19)-(23); $k_{12} = 1 - \frac{k_{12}k_{13}}{k_{13}}$ (see Eq. (35))

K_{rj} = j 'th root of Eq. (2); $j = 1$ to c

K_{sj} = j 'th root of Eq. (3); $j = 1$ to c

M = number of theoretical stripping plates

N = number of theoretical rectifying plates

q = total heat required to vaporize one mole of feed divided by the molal latent heat of vaporization

$r = 1 - (\log K_{ch}/K_{rl})/(\log K_{ch}/K_{el})$

$$s_j = \frac{a_j}{a_k} \left(\frac{K_{rj}}{K_{ch}} \right)^k$$

$$S_j = \frac{b_j}{b_k} \left(\frac{K_{sj}}{K_{ch}} \right)^{M+1}$$

$(sr)_i = \frac{Dx_{Bi}}{Bx_{Bi}}$ the separation ratio of the i 'th component

$$u_B = \frac{x_{D_B}}{1 - \frac{\rho}{a_B K_{rB}}} = \frac{\rho}{1 - \rho} - \sum_{i \neq B} \frac{x_{Bi}}{a_i} - 1$$

(see Eqs. (6), (7))

$$U_L = \frac{x_{B_L}}{1 - \frac{\sigma}{a_L K_{el}}} = \frac{\sigma}{1 - \sigma} - \sum_{i \neq L} \frac{x_{Bi}}{a_i} - 1$$

(see Eqs. (8), (9))

x_i = mole fraction of i 'th component in liquid; x_{Di} = mole fraction of i 'th component in top product

X_{Fi} = mole fraction of component i in total feed to column

y_i = mole fraction of i 'th component in vapor

$$Z = \sum_c s_j / \sum_c S_j$$

SUBSCRIPTS:

c = total number of components, or component having the largest value of a in the system

h = heavy key component

H = component having a less than a_h

i = i 'th component or i 'th K_r or K_s . Components numbered so that $a_1 < a_2 < \dots < a_h < a_i < \dots < a_c$. K_r 's and K_s 's numbered so that $K_c < \dots < K_1$

j = j 'th component

L = light key component

L = component having a greater than a_L

GREEK LETTERS:

α_i = volatility ratio of i 'th component, assumed constant. $a_i = (y_i/x_i)/(y/x$ for base component). Base component selected arbitrarily

ρ = moles liquid overflowing from any plate in rectifying section, divided by moles vapor entering same plate from below; assumed constant

σ = moles vapor leaving any plate in stripping section, divided by moles liquid entering same plate from above; assumed constant

θ = a root, having a value somewhere between a_h and a_L of Eq. (28)

MATHEMATICAL SYMBOLS:

\neq is not equal to

Σ = summation symbol; $\sum_{j=h}^c f(j) = f(j_1) + \dots + f(j_3)$

$\sum_c f(j)$ signifies $\sum_{j=1}^c f(j)$

$<$ = inequality symbol

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NOMOGRAPH FOR THE van LAAR EQUATION

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SINCE the vapor-liquid equilibrium data, basic informations needed in the design of distilling columns, are often lacking, their prediction is of great value to the design engineer. Under low pressure where Dalton's law of partial pressure applies, the following expression, derived on the assumption of ideal liquid solution where Raoult's law holds, can be used to predict vapor-liquid equilibrium data:

$$y_1 = P' x_1 \quad (1)$$

If the liquid solution is nonideal, the liquid concentration, x , in Equation (1) should be multiplied by an activity coefficient γ as represented by:

$$y_1 = P' \gamma x_1 \quad (2)$$

As most commercial distillations are carried out under atmospheric or lower pressure, Equation (2) is a convenient equation to predict vapor-liquid equilibrium data of a system of any number of components provided the activity coefficient can be estimated.

A prediction of the activity coefficient is made by integration of the Gibbs-Duhem equation

$$\Sigma x_i d\ln y_i = 0$$

For binary systems, several integrated expressions (1, 2, 7-15) have been proposed among which the van Laar form rearranged as follows by Carlson and Colburn (1) has been found to fit many systems well:

$$\log y_1 = \frac{A'}{\left(1 + \frac{A'x_1}{B'x_2}\right)^2} \quad (3a)$$

$$\log y_2 = \frac{B'}{\left(1 + \frac{B'x_2}{A'x_1}\right)^2} \quad (3b)$$

While (15) rearranged the van Laar equation to include the effect of temperature on the activity coefficient and gave the following form with van der Waal's constant:

$$T \log y_1 = \left[\frac{a_{21}}{x_1 + b_1} \right]^2 \quad (4a)$$

$$T \log y_2 = \left[\frac{a_{12}}{x_2 + b_2} \right]^2 \quad (4b)$$

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Since a_{12} , a_{21} , b_1 , b_2 , are all constants, these expressions can be thus rearranged:

$$T \log y_1 = A / \left(\frac{Ax_1}{Bx_2} + 1 \right)^2 \quad (5a)$$

$$T \log y_2 = B / \left(\frac{Bx_2}{Ax_1} + 1 \right)^2 \quad (5b)$$

where A, B = constants characteristic of each particular system. By comparing Equation (3a) and (3b) with (5a) and (5b), it is found that

$$A = TA' \quad (6a)$$

$$B = TB' \quad (6b)$$

Let $C = A/B$ and $X = x_1/x_2 = x_1/(1-x_1)$. Equation (5) can be transformed into:

$$T \log y_1 = A / (CX + 1)^2 \quad (7a)$$

$$T \log y_2 = B / \left(\frac{1}{CX} + 1 \right)^2 \quad (7b)$$

Dividing Equation (7b) by (7a),

$$(\log y_2 / \log y_1) = CX^2$$

is obtained, or

$$C = \frac{1}{X^2 \log y_1} \quad (8)$$

According to Carlson and Colburn (1), composition of the azeotrope generally furnishes the best basis to evaluate constants of the van Laar equation if the azeotrope composition is in the middle of the composition range, between $x_1 = 0.25$ and $x_1 = 0.75$.

At azeotropic point, $x = y$, Equation (2) can be reduced to

$$\gamma'_1 = \pi / P'_1, \quad \gamma'_2 = \pi / P'_2$$

When total pressure, π , under which the composition of the azeotrope is determined, is one atmosphere:

$$\gamma'_1 = \frac{1}{P'_1}, \quad \gamma'_2 = \frac{1}{P'_2} \quad (9)$$

Where

γ'_1 and γ'_2 = activity coefficient of the components 1 and 2 in liquid solution at azeotropic point under one atmosphere

P'_1 and P'_2 = vapor pressure of pure components 1 and 2 at azeotropic temperature under one atmosphere

Substituting Equation (9) into Equation (8),

$$C = \frac{1}{X^2 \log P'_1} \quad (10)$$

is obtained.

Where X' is x'_1/x'_2 .

Taking the logarithm on both sides of Equation (10) and rearranging, the following expression, which is the basis of nomograph (I), is obtained:

$$\begin{aligned} & \log (1/X'^2) + \log \log P'_1 \\ & = \log C + \log \log P'_1 \end{aligned} \quad (11)$$

Taking the logarithm on both sides of Equation (7), the following expressions, which are plotted as nomograph (II) are obtained:

$$\begin{aligned} & \log T + \log \log y_1 = \log A \\ & - \log (CX + 1)^2 \end{aligned} \quad (12a)$$

Similarly, Equation (7b) can be transformed into the following form after taking the logarithm on both sides

$$\begin{aligned} & \log T + \log \log y_2 = \log B \\ & - \log \left(\frac{1}{CX} + 1 \right)^2 \end{aligned} \quad (12b)$$

The same nomograph (II) can be used to solve Equation (12b) provided A and CX scales are used for B and $1/CX$ and y_2 read from the scale of y_1 .

In case the activity coefficient is less than unity, $\log \gamma$ will be negative and it is impossible to take the logarithm on Equations (7a) and (7b). However, if a negative sign is added to both sides, Equation (7a) and (7b) can be transformed into:

$$T \log (1/y_1) = -A / (CX + 1)^2 \quad (13a)$$

$$T \log (1/y_2) = -B / \left(\frac{1}{CX} + 1 \right)^2 \quad (13b)$$

Since constants A and B in the van Laar equation are negative in the case of a system whose components have an activity coefficient less than unity, negative values of them must be positive and no mathematical difficulty is involved in taking the logarithm on Equation (13).

$$\begin{aligned} & \log T + \log \log (1/y_1) \\ & = \log (-A) - \log (CX + 1)^2 \end{aligned} \quad (14a)$$

$$\begin{aligned} & \log T + \log \log (1/y_2) = \log (-B) \\ & - \log \left(\frac{1}{CX} + 1 \right)^2 \end{aligned} \quad (14b)$$

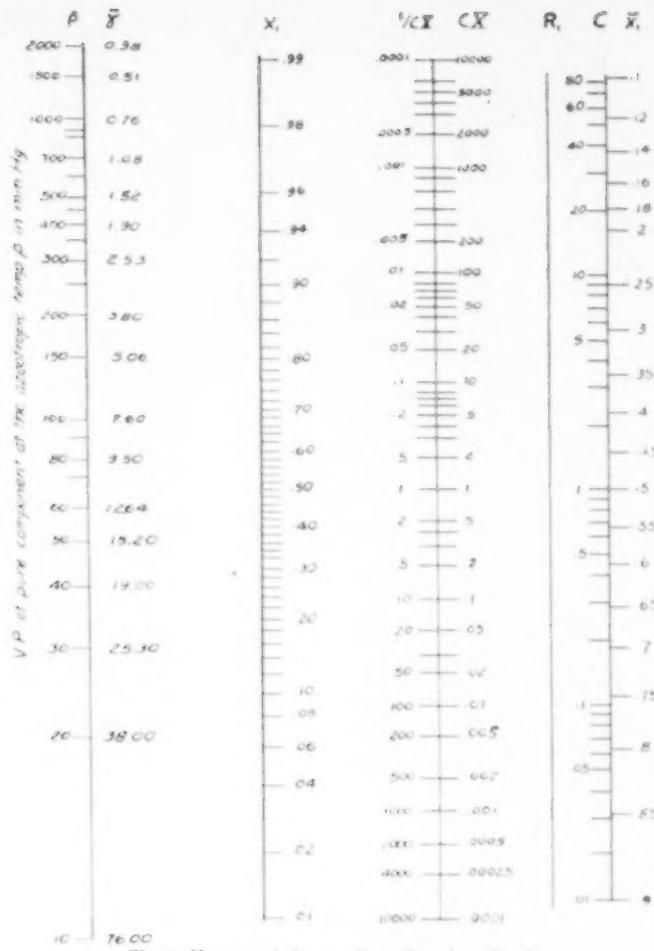


Fig. 1. Nomograph for van Laar Equation (No. I)

Equations (14a) and (14b) can be solved by the same nomograph (II) provided $(-A)$ or $(-B)$ is read on A or B scale and the value obtained from γ axis should be $1/\gamma$.

Nomographs (I) and (II) can be used as a quick and convenient way to solve the van Laar equation for the estimation of vapor-liquid equilibrium data from azeotropic data which have been extensively collected by Horsley (3). Their use is outlined as:

Evaluation of constants A and B :

- On nomograph (I) align x'_1 on x'_1 scale with P'_1 on P' scale to intersect a point on R_1 , the first reference line. Align this point of intersection with P'_2 on P' scale to obtain value of C .

- Align C with x'_1 on x'_1 scale to read CX' and $1/CX'$.

- On nomograph (II), align t' , azeotropic boiling point in °C, on t scale with γ_1 , read from a stationary scale of γ' from value of P'_1 on nomograph (I) to intersect a point on R_2 , a second reference line; then align this point with CX to obtain value of constant A . Align t' on t scale with γ'_2 on γ scale to intersect a point on R_2 ; then align this point with value of $1/CX'$ on CX' scale to read value of B from its scale.

Evaluation of activity coefficients γ_1 and γ_2 for components in binary solution at temperature t with their mole fraction equal to x_1 and x_2 :

- On nomograph (I), align C with x_1 on x scale to read CX and $1/CX$ on the latter's scale.

- On nomograph (II), align CX with constant A to intersect a point

on R_2 ; align this point on R_2 with t on temperature scale to obtain γ_1 ; align $1/CX$ with B to intersect a point on R_2 ; align this point with t to get a value of γ_2 along its scale.

The same procedure can be used to read the activity coefficient of a binary system where the latter is less than unity provided the final value of the activity coefficient, γ , from the scale is equal to $1/\gamma$.

To illustrate use of the nomographs, two sample problems are presented.

Illustration 1: (4) The azeotropic composition of the ethanol-benzene system is 44.8 mole % ethanol with a boiling point of 68.24° C. at 760 mm. Hg. At 68.24° C., the vapor pressure of pure benzene is 517 mm. Hg. and that of ethanol is 506 mm. Hg. Evaluate the activity coefficient for a solution containing 10 mole % ethanol.

Evaluation of constants A and B : Vapor pressure data are given as follows:

$$P'_1 = 517 \text{ mm. Hg}$$

$$P'_2 = 506 \text{ mm. Hg}$$

On nomograph (I), connect the point 0.552 on x'_1 scale with 517 on P' scale to intersect R_1 scale. Connect this point on R_1 with 506 on P' scale and extend the line to cut C scale at a value of 0.66. Connect 0.66 on C scale to 0.552 on x_1 scale to obtain 0.8 of CX' on CX scale and 0.182 of $1/CX'$ on $1/CX$ scale.

On nomograph (II), connect 68.24 on t scale with 1.47 on γ scale to obtain a point of intersection with R_2 scale. Connect this point on R_2 scale with 0.8 on CX scale to obtain $A = 187$ on A or B scale. Similarly, connect 68.24 on t scale with 1.50 on γ scale to obtain a point of intersection on R_2 which is then connected with the value of $(1/CX) = 1.2$ on CX scale to obtain $B = 282$.

Evaluation of γ_1 and γ_2 : On nomograph (I), connect 0.66 on C scale with 0.89 on x_1 scale to read 5.8 and 0.182 on CX and $1/CX$ scales respectively. On nomograph (II), connect 5.8 on CX scale with 187 on A scale to intersect a point on R_2 . The line connecting this point of intersection on R_2 with a point of 72.4 on t scale intersects γ scale at a point of 1.027 which is the activity coefficient of benzene; the true value given by International Critical Table (6) is 1.02. Similarly, on nomograph (II), connect 0.18 on CX scale with 282 on B scale to give a point of intersection on R_2 . Connect this point on R_2 with 72.4 on t scale and continue the line

to γ scale; the intersection gives the answer of $\gamma_2 = 3.7$ on γ scale; International Critical Tables give a true value of γ_2 equal to 3.14.

Illustration 2: Estimate the activity coefficient for a solution of acetone and chloroform with the mole fraction of the former equal to 0.796 at a temperature of 59.4°C.

The mixture of acetone and chloroform has an azeotropic boiling point of 64.5°C. at a mole % of acetone equal to 34.5 (3).

From vapor pressure data,

$$P'_1 = 1040 \text{ mm. Hg}$$

$$P'_2 = 785 \text{ mm. Hg}$$

Evaluation of constants A and B. On nomograph (I) connect the point 0.345 on x'_1 scale with 1040 on P' scale to intersect R'_1 scale. Connect this point on R'_1 with 785 on P' scale and extend the line to cut C scale at a value of 3.7. Connect 3.7 on C scale with 0.345 on x_1 scale to obtain 2 and 0.5 on CX and 1/CX scales respectively. On nomograph (II), connect 64.5 on t scale with $(1/\gamma'_1) = (1/0.731) = 1.368$ on γ scale to obtain a point of intersection with R'_2 scale. Connect this point on R'_2 scale with 2 on CX scale to obtain A value of 410 on A scale. Similarly, connect 64.5 on t scale with $(1/\gamma'_2) = (785/760) = 1.032$ on γ scale to obtain a point of intersection with R'_2 scale. Connect this point of intersection with 0.5 on CX scale to obtain value of 10.2 for B on its scale.

Evaluation of γ_1 and γ_2 . On nomograph (I) connect a point 3.7 on C scale with 0.796 on x_1 scale to read 14 and 0.08 on CX and 1/CX scales respectively. On nomograph (II), connect 14 on CX scale with a point of 410 on A scale to intersect a point on R'_2 . The line connecting this point of intersection on R'_2 with a point of 59.4 on t scale intersects γ scale at a point of 1.012. The activity coefficient of acetone is therefore equal to $(1/1.012) = 0.986$, compared with 0.96 from the literature (5).

Similarly, on nomograph (II), connect 0.08 on 1/CX scale with 10.2 on B scale to give a point of intersection on R'_2 scale. Connect this point on R'_2 with a point of 59.4 on t scale to read a value of 1.067 on γ scale. Therefore the activity coefficient of chloroform is equal to $(1/1.067) = 0.937$ compared with 0.94 from the literature (5).

Composition of the azeotrope generally furnishes the best basis to evaluate the van Laar equation constants for a binary system when the azeotropic com-



Fig. 2. Nomograph for van Laar Equation (No. II)

position is between $x_1 = 0.25$ and $x_1 = 0.75$. A measurement of a single set of equilibrium liquid and vapor compositions, together with knowledge of vapor pressure of the pure components, furnishes a better basis for the evaluation of constants A and B, if the azeotropic composition is outside the middle range or if there is no azeotropism. The same nomograph can be used in this case for the evaluation of van Laar equation constants if the procedures presented below are followed.

First, calculate the activity coefficient from a single measurement of equilibrium vapor-liquid composition and vapor pressure of the pure components at the same temperature by the equation

$$\gamma_1 = \pi y_1 / P'_1 x_1 \quad (2a)$$

$$\gamma_2 = \pi y_2 / P'_2 x_2 \quad (2b)$$

On nomograph (I) align values γ_1 calculated from Equation (2a) on γ scale

with x_1 on x scale to intersect a point on R'_1 . Align this point with γ_2 calculated from Equation (2b) on γ scale to obtain value of C on its scale. Align C with x_1 on x scale to read value of CX and 1/CX.

On nomograph (II) align γ_1 calculated from Equation (2a) on γ scale with value of temperature on t scale to intersect a point on R'_2 . Align this point on R'_2 with CX to obtain value of A on its scale. Similarly, align γ_2 calculated from Equation (2b) with t to intersect a point on R'_2 . Connect this point on R'_2 with 1/CX to intersect a value of B on its scale. Once constants A and B in the van Laar equation are found, evaluation of the activity coefficient can follow the similar procedure presented.

Few reliable data are available from which an activity coefficient in a ternary system can be calculated. Correlation of activity coefficients in such systems has

TABLE I—COMPARISON OF ACTIVITY COEFFICIENT OF ISOPROPYL ETHER

| Temperature, °C. | Mole Fraction of Isopropyl Ether x_1 | Cx | Activity Coefficient of Isopropyl Ether, γ_1 | | |
|------------------|---|------|---|--------------------------|-------------------|
| | | | Nomograph | Carlson-Colburn Equation | Experimental Data |
| 76 | 0.09 | 0.07 | 2.4 | 2.35 | 2.9 |
| 72.5 | 0.18 | 0.18 | 2.1 | 2.1 | 2.2 |
| 70 | 0.28 | 0.28 | 1.81 | 1.80 | 1.85 |
| 68.2 | 0.38 | 0.45 | 1.58 | 1.60 | 1.65 |
| 67.6 | 0.47 | 0.65 | 1.45 | 1.45 | 1.45 |
| 66.8 | 0.58 | 0.90 | 1.32 | 1.32 | 1.32 |
| 66.3 | 0.66 | 1.5 | 1.17 | 1.23 | 1.23 |
| 66.2 | 0.77 | 2.4 | 1.08 | 1.10 | 1.10 |

TABLE 2—COMPARISON OF ACTIVITY COEFFICIENT OF ISOPROPYL ALCOHOL

| Temperature, °C. | Mole Fraction of Isopropyl Ether x_1 | Activity Coefficient of Isopropyl Alcohol, γ_2 | | | | |
|------------------|---|---|--------|-----------|--------------------------|-------------------|
| | | 1 x_2 | Cx | Nomograph | Carlson-Colburn Equation | Experimental Data |
| 76 | 0.09 | 13 | 1.0668 | ... | ... | ... |
| 72.5 | 0.18 | 6 | 1.028 | 1.028 | 1.028 | 1.028 |
| 70 | 0.28 | 4.2 | 1.054 | 1.08 | 1.054 | 1.054 |
| 68.2 | 0.38 | 2.5 | 1.12 | 1.16 | 1.15 | 1.15 |
| 67.6 | 0.47 | 1.7 | 1.22 | 1.25 | 1.25 | 1.25 |
| 66.8 | 0.58 | 1.1 | 1.36 | 1.40 | 1.45 | 1.45 |
| 66.3 | 0.66 | 0.7 | 1.6 | 1.6 | 1.6 | 1.6 |
| 66.2 | 0.77 | 0.46 | 1.95 | 1.95 | 1.97 | 1.97 |
| 66.6 | 0.88 | 0.20 | 2.7 | 2.7 | ... | ... |
| 67.3 | 0.97 | 0.049 | 3.5 | 3.7 | ... | ... |

been developed by Wohl (13). The most convenient form requiring minimum data is of the following van Laar form involving only six constants, all of which can be evaluated from data on three individual binary systems.

$$\log \gamma_1 = \frac{x_2^2 A'_{1-2} \left[\frac{A'_{2-1}}{A'_{1-2}} \right]^2 + x_3^2 A'_{1-3} \left[\frac{A'_{3-1}}{A'_{1-3}} \right]^2}{\left[x_1 + x_2 \frac{A'_{2-1}}{A'_{1-2}} + x_3 \frac{A'_{3-1}}{A'_{1-3}} \right]^2} + \frac{x_2 x_3 \frac{A'_{2-1}}{A'_{1-2}} \frac{A'_{3-1}}{A'_{1-3}} \left[A'_{1-2} + A'_{1-3} - A'_{2-1} - A'_{3-1} \right]}{\left[x_1 + x_2 \frac{A'_{2-1}}{A'_{1-2}} + x_3 \frac{A'_{3-1}}{A'_{1-3}} \right]^2} \quad (15)$$

In Equation (15) the constants A'_{1-2} and A'_{2-1} correspond to A/T and B/T where A and B are van Laar constants of a binary system of components 1 and 2. Similar equations for γ_2 and γ_3 are obtained by changing the subscripts on all terms in the equation in accordance with the following schedule of rotation:

Subscripts in Equation (15) for

| $\log \gamma_1$ | $\log \gamma_2$ | $\log \gamma_3$ |
|-----------------|-----------------|-----------------|
| 1 | 2 | 3 |
| 2 | 3 | 1 |
| 3 | 1 | 2 |

By means of Equation (15) activity coefficients of all components in a ternary system can be estimated from the van Laar constants of three binary systems which in turn can be quickly evaluated from this nomograph. The amount of time involved in evaluating an activity coefficient of such a complex

system can be greatly reduced by use of this nomograph.

A comparison of activity coefficients read from the nomographs with those calculated directly from Equation (3a)

and (3b) given by Carlson and Colburn (1) and with experimental data (14) for a system of isopropyl ether and isopropyl alcohol has been made, and listed in Tables 1 and 2. It is observed from the tables that the values read from the nomographs gave an excellent agreement with the experimental data as well as those calculated from Equation (3a) and (3b). Since only little time is involved in evaluating the activity coefficient by means of the present nomographs, its use in calculation of distillation design is recommended.

Notation

A, B = van Laar equation constants, characteristic of a system, independent of temperature and composition

$$A'_{1-2} = A/T$$

$$A'_{2-1} = B/T$$

a, b = van der Waals' constants

1, 2 = subscript denoting components 1 and 2

a_{21}, a_{12} = constants for the binary system

$$C = A/B = \text{constant}$$

P° = vapor pressure of pure component at temperature of solution

P'_1, P'_2 = vapor pressure of pure components 1 and 2 in millimeters mercury at azeotropic boiling point of solution under one atmosphere

t' = azeotropic boiling point of a binary solution under one atmosphere, °C.

$$T = \text{temperature, } ^\circ\text{K.}$$

x_1, x_2 = mole fraction of components 1 and 2 in a solution at temperature t

x'_1, x'_2 = azeotropic composition of components 1 and 2 under one atmosphere expressed in terms of mole fraction

$$X = x_1/x_2$$

$$X' = x'_1/x_2$$

π = total pressure, atmospheres

γ_1, γ_2 = activity coefficient of components in same solution

γ'_1, γ'_2 = activity coefficient of components 1 and 2 in azeotropic solution under one atmosphere

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ALGEBRAIC CALCULATION OF DISTILLATION COLUMNS

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A. J. V. Underwood, in a recent series of articles, presented a set of distillation equations for multicomponent systems. These equations relate the number of plates in a section to the concentrations of the various components at the ends of the section. In the present paper, by rearrangement of these basic equations to allow use of determinants, a fairly rapid solution for multicomponent systems has been found. The solution may, by successive approximation, be made as exact as desired, and is applicable to any multicomponent system where the initial assumptions of constant relative volatility and constant flows can be made.

Two useful types of solution have been found. In the first, the distribution of two components, the keys, is fixed, the distribution of the remaining components, the diluents, is assumed, and a series of calculations is made with varying proportions between rectifying and stripping plates. The total plates are plotted to determine the optimum proportion of plates between the sections, that is, the minimum number of total plates necessary at the selected reflux. At this value of plates the distribution of the diluents is checked, and if necessary a recalculation is made. In the second method the distribution of three components is fixed, and the single corresponding plate picture is calculated.

METHODS available at the present time for the calculation of distillation columns can in general be divided into two classifications, namely those which proceed from plate to plate through the column and those which calculate entire sections at once, or group methods. The plate-to-plate procedures are necessarily tedious, becoming more so as the number of components and the number of plates increase. Group methods are considerably simpler to use, and are for the most part based on only two components, so that they are equally rapid in use no matter what the number of components or the number of plates. On the other hand, the plate-to-plate procedures possess the advantage that they are exact under the basic assumptions made, whereas the presently available group methods based on the same assumptions are still only approximate. Thus, in addition to the error introduced by the basic assumptions, a second error is added through the use of the group methods, and while the first error is to some extent predictable, the second error is essentially unknown, and uncontrollable. A group method which would

be exact under the basic assumptions would be very desirable.

In the opinion of the authors, any group method which is to be at all rapid must be based on the assumptions of constant relative volatility in any section and constant molal flows in any section. The necessary fashioning of material balance and equilibrium equations into a geometric progression either would be too difficult to accomplish or would lead to an exceedingly complex relation if the refinement of vapor-liquid equilibrium constants or heat balances were added. The assumptions of constant relative volatility and constant molal flows are certainly inexact, and considerable criticism has been leveled at the use of methods which employ them. However, in regular systems, such as hydrocarbon systems, they are sufficiently accurate to be used for many studies. Moreover, in view of the low accuracy to which plate efficiencies are known at present, further complication of plate calculations by the use of equilibrium constants and heat balances hardly appears justified in most cases.

Group methods are also incapable of

calculating the distribution of components other than the keys. The calculation of these distributions can be made with exactness by plate-to-plate methods, but only through tedious trial-and-error calculations. While the calculation of the distribution of all components other than the keys is probably seldom desired, a group method which would also allow their determination would be valuable.

Equations of Underwood for sections of finite plates (1-3) can be solved to obtain both plate numbers and the exact distribution of all components under the assumptions of constant relative volatility and constant flows. While the solution is not easy, it is more rapid than plate-to-plate calculations for many systems, and consequently should find considerable use, both as a design method and as a source of data for the development and evaluation of empirical calculation methods.

Basic Equations. Inasmuch as the equations of Underwood constitute the starting point from which solutions of the column presented in this paper evolved, a brief review of these equations is also presented, employing as an example a three-component system. A parameter, ϕ , is first defined by the equation

$$-\frac{V}{d} = \frac{a_A d (x_A)_d}{a_A - \phi} + \frac{a_B d (x_B)_d}{a_B - \phi} + \frac{a_C d (x_C)_d}{a_C - \phi} \quad (1)$$

where

- V = rectifying section vapor flow, moles/mole of feed
- d = total top product, moles/mole of feed
- x_i = mole fraction of component i in a liquid
- a_i = relative volatility of component i , all relative volatilities to be based on the same reference component

Subscripts *A*, *B*, and *C* refer to components *A*, *B*, and *C*, where *A* is the most volatile component, *B* is the next most volatile, etc. Subscript *d* refers to the concentration of a component in the top product.

From Equation (1), three values of ϕ may be calculated if all other variables are set. The largest of these, ϕ_1 , lies numerically between a_A and a_B . The next largest, ϕ_2 , lies between a_B and a_C , and the smallest, ϕ_3 , between a_C and zero. Equation (1) can thus be written three times, in ϕ_1 , ϕ_2 , and ϕ_3 , yielding the three equations (1), (1') and (1'').

A similar equation written for the stripping section defines the parameter, ϕ' . Thus,

$$-l'' = \frac{a_A b(x_A)_b}{a_A - \phi'} + \frac{a_B b(x_B)_b}{a_B - \phi'} + \frac{a_C b(x_C)_b}{a_C - \phi'} \quad (2)$$

where

l'' = stripping section vapor flow, moles/mole of feed

b = total bottom product, moles/mole of feed

Subscript *b* refers to the concentration of a component in the bottom product.

Again, from Equation (2) three values of ϕ' may be calculated if the concentration in the bottom product of all three components is fixed. The largest of these ϕ' values, ϕ'_1 , lies numerically above a_A , the next largest, ϕ'_2 , between a_A and a_B , and the smallest, ϕ'_3 , between a_B and a_C . Three equations of type (2) can also be written in ϕ'_1 , ϕ'_2 , and ϕ'_3 . Equations (2), (2'), and (2'').

By combination of Equations (1) with material balance and equilibrium equations, three equations can be written relating the concentrations of *A*, *B*, and *C* in the liquid on the feed plate to the total number of rectifying plates and the values of ϕ_1 , ϕ_2 , and ϕ_3 . Thus,

$$\frac{\frac{a_A x_A}{a_A - \phi_1} + \frac{a_B x_B}{a_B - \phi_1} + \frac{a_C x_C}{a_C - \phi_1}}{\frac{a_A x_A}{a_A - \phi_2} + \frac{a_B x_B}{a_B - \phi_2} + \frac{a_C x_C}{a_C - \phi_2}} = \left(\frac{\phi_2}{\phi_1} \right)^m \quad (3)$$

and two other similar equations, Equation (3') in ϕ_2 and ϕ_3 , and Equation (3'') in ϕ_1 and ϕ_3 . For the sake of brevity and to facilitate calculations these equations are rewritten here as:

$$\frac{A_1 x_A + B_1 x_B + C_1 x_C}{A_2 x_A + B_2 x_B + C_2 x_C} = \phi_{21}^m \quad (3)$$

$$\frac{A_2 x_A + B_2 x_B + C_2 x_C}{A_3 x_A + B_3 x_B + C_3 x_C} = \phi_{32}^m \quad (3'')$$

$$\frac{A_1 x_A + B_1 x_B + C_1 x_C}{A_3 x_A + B_3 x_B + C_3 x_C} = \phi_{31}^m \quad (3'')$$

where

x_i with no further subscript denotes the mole fraction of component *i* in the liquid on the feed plate.

$$A_1 = \frac{a_A}{a_A - \phi_1}$$

$$B_1 = \frac{a_B}{a_B - \phi_1}, \text{ etc.}$$

$$\phi_{21} = \frac{\phi_2}{\phi_1}, \text{ etc.}$$

m = rectifying plates, including the feed plate

Only two of Equations (3), (3'), and (3'') are independent and of simultaneous use in solutions of the column. Any two of the three equations can, of course, be used.

Three similar equations can be written employing the values of ϕ'_1 , ϕ'_2 , and ϕ'_3 obtained from Equation (2). Again, only two of these equations are independent.

$$\frac{A'_1 x_A + B'_1 x_B + C'_1 x_C}{A'_2 x_A + B'_2 x_B + C'_2 x_C} = \phi'_{21}^m \quad (4)$$

$$\frac{A'_2 x_A + B'_2 x_B + C'_2 x_C}{A'_3 x_A + B'_3 x_B + C'_3 x_C} = \phi'_{32}^m \quad (4'')$$

$$\frac{A'_3 x_A + B'_3 x_B + C'_3 x_C}{A'_1 x_A + B'_1 x_B + C'_1 x_C} = \phi'_{31}^m \quad (4'')$$

where

$$A'_1 = \frac{a_A}{a_A - \phi'_1}, \quad B'_1 = \frac{a_B}{a_B - \phi'_1}, \text{ etc.}$$

$$\phi'_{32} = \frac{\phi'_3}{\phi'_2}, \text{ etc.}$$

m = stripping plates, including the reboiler but not the feed plate

Thus, for a four-component system, Equation (1) becomes

$$l' = \frac{a_A d(x_A)_d}{a_A - \phi} + \frac{a_B d(x_B)_d}{a_B - \phi} + \frac{a_C d(x_C)_d}{a_C - \phi} + \frac{a_D d(x_D)_d}{a_D - \phi}$$

and Equation (3) becomes

$$\frac{A_1 x_A + B_1 x_B + C_1 x_C + D_1 x_D}{A_2 x_A + B_2 x_B + C_2 x_C + D_2 x_D} = \phi_{21}^m$$

Three equations similar to Equation (3) and three equations similar to Equation (4) are now independent and simultaneously useful in solutions of the column.

The above résumé of the equations of Underwood is as brief as possible, and is presented here, at least in part, as the best method of introducing the notation to be used in later discussions. For a complete treatment of the basic equations, reference should be made to the various papers of Underwood. In the last of these papers (3), Underwood proposes a solution for rectifying and stripping plates. However, the method is somewhat cumbersome, and no further method is proposed by which the distribution of components other than the keys can be calculated. The authors believe the following method of solution of the column to be both more convenient and more useful, since the distribution of all components can be calculated as exactly as desired.

Exact Solution of Column. It is illuminating before going into the mathematical equations to look at the variables involved in multicomponent column calculations. In the design of a new column, complete data are usually furnished on the feed to the column and the task to be accomplished with it, that is, the separation of the key components required. The column pressure is fixed, fixing the volatilities of the components, and, as custom has it, reflux is next fixed. However, the vapor flow in the rectifying section could equally well be set. It can then be shown, as follows, that only one further main variable can be fixed no matter how many components are present.

For the ternary system, *A*, *B*, and *C*, the independent Equations (1), (1'), (1''), (2), (2'), (2''), (3), (3'), (4), and (4'') are applicable, comprising ten equations in all. If, for example, components *A* and *B* are the keys and *C* the diluent, Equations (1) contain as unknowns, $d(x_C)_d$, ϕ_1 , ϕ_2 , and ϕ_3 . Similarly, Equations (2) contain the new unknowns, ϕ'_1 , ϕ'_2 , and ϕ'_3 , $b(x_B)_b$ being related to $d(x_C)_d$ through the known quantity of component *C* in the feed. Equation (3) and Equation (4) contain the additional unknowns x_A , x_B , x_C ,

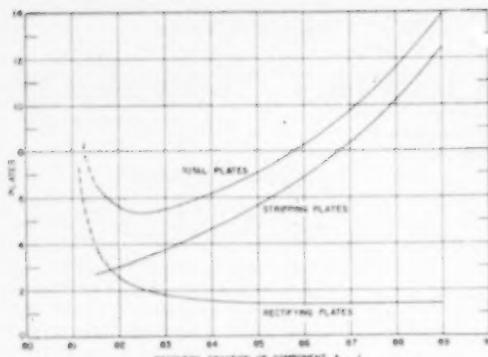


Fig. 1. Plate Numbers vs. Diluent Recovery Fraction.

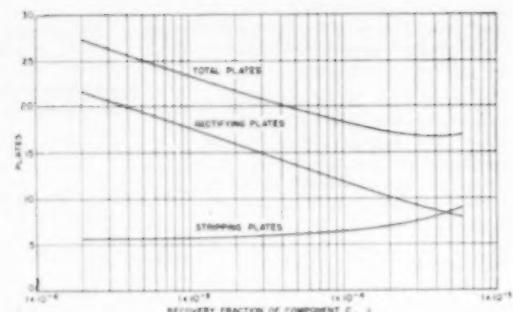


Fig. 2. Plate Numbers vs. Diluent Recovery Fraction.

and m . Again x_C is not an unknown since it is related to x_A and x_B through the equation:

$$x_A + x_B + x_C = 1$$

The unknowns, $d(x_1)_d$, ϕ_1 , ϕ_2 , ϕ_3 , ϕ'_1 , ϕ'_2 , ϕ'_3 , x_A , x_B , n , and m can be seen to number eleven, outnumbering the equations by one, and consequently one further variable can be fixed.

Any additional component creates as many equations as unknowns. Thus a further component D , for example, would add equations in ϕ_4 and ϕ'_4 ; Equations (1'') and (2''), and two more ratio equations, one in the rectifying section, (3''), and one in the stripping section, (4''); but component D also adds the unknowns, ϕ_4 , ϕ'_4 , $d(x_4)_d$, and x_B .

As the one additional variable to be fixed, certainly none of the ϕ values, ϕ' values, or x_i values can logically be set, since these unknowns are only aids in calculation. However, a third recovery fraction, or n , or m could be set. There is, in general, in practical work no reason to fix as the last variable a given number of stripping or rectifying plates. Practically, rather, it is desired to calculate optimum total plates, in other words, minimum total plates which will accomplish the desired separation of the key components at the chosen reflux. Or it is desired to fix the recovery fraction of a third component, that is, the fraction of the amount in the feed of a third component which is removed in the top product, and calculate the number of rectifying and stripping plates required. These two cases, requiring a different approach to the solution, will be treated separately in the following sections.

Fixed Distribution of a Third Component. Though predetermining the recovery fraction of a third component

was proposed, caution must be exercised in doing so. The recovery fraction of a third component must, of course, maintain the same order within the recovery fractions of the components as its relative volatility. But, beyond that, further restrictions exist which put a lower and upper limit on the recovery fraction only within which one will find a physically real solution to plates. Calculations show, depending on which limit is approached, that infinite plates are needed in either the stripping or rectifying section (see Figs. 1 and 2). If, in the calculations a value of the third component recovery fraction was picked outside those limits permitted, no meaningful solution was found possible.

However, assuming that some plausible recovery fraction for the third component in a ternary system has been selected, and the ϕ and ϕ' values obtained by solving Equations (1) and (2), the corresponding number of rectifying and stripping plates must then be determined from Equations (3), (3'), (4), (4'), and (5). These five equations contain, besides the unknowns, n and m , the unknowns, x_A , x_B , and x_C , the values of which, in general, are of limited interest, except as an aid in determining m and n . These feed plate compositions serve the same purpose as the ϕ and ϕ' values, and if all of these intermediate unknowns could be eliminated, the solution for plates in the column would be much more direct. The difficulties of removing the ϕ and ϕ' values from the mathematical system are very great. However, none of this complexity occurs in the removal of the feed plate concentrations, if determinants are made use of as follows:

Equation (3) is rearranged to

$$A_1 x_A + B_1 x_B + C_1 x_C = (\phi_{21}^n)(A_2 x_A + B_2 x_B + C_2 x_C) \quad (6)$$

and the terms are then collected to give

$$(A_1 - A_2 \phi_{21}^n)x_A + (B_1 - B_2 \phi_{21}^n)x_B + (C_1 - C_2 \phi_{21}^n)x_C = 0 \quad (7)$$

Applying the same process to Equations (3'), (4), and (4'), the following set of equations is obtained:

$$(A_2 - A_3 \phi_{32}^n)x_A + (B_2 - B_3 \phi_{32}^n)x_B + (C_2 - C_3 \phi_{32}^n)x_C = 0 \quad (8)$$

$$(A'_2 - A'_3 \phi'_{32}^m)x_A + (B'_2 - B'_3 \phi'_{32}^m)x_B + (C'_2 - C'_3 \phi'_{32}^m)x_C = 0 \quad (9)$$

$$(A'_1 - A'_2 \phi'_{21}^m)x_A + (B'_1 - B'_2 \phi'_{21}^m)x_B + (C'_1 - C'_2 \phi'_{21}^m)x_C = 0 \quad (10)$$

It is possible to use Equation (5) in conjunction with Equations (7) and (8), assuming a value of n , in order to solve for the feed plate compositions. These feed plate compositions would then be used to solve for m from both Equations (9) and (10), assuming new values of n until both values of m checked. Instead, it is proposed not to use Equation (5), but to combine both rectifying section Equations (7) and (8), with one of the stripping section equations, say Equation (9). These three equations in the three unknowns, x_A , x_B , and x_C , are all equal to zero, homogeneous, and it is well known that in order to obtain a meaningful solution, the determinant of the coefficients of the variables must be equal to zero.

Thus:

$$\begin{vmatrix} A_1 - A_2 \phi_{21}^n & B_1 - B_2 \phi_{21}^n & C_1 - C_2 \phi_{21}^n \\ A_2 - A_3 \phi_{32}^n & B_2 - B_3 \phi_{32}^n & C_2 - C_3 \phi_{32}^n \\ A'_2 - A'_3 \phi'_{32}^m & B'_2 - B'_3 \phi'_{32}^m & C'_2 - C'_3 \phi'_{32}^m \end{vmatrix} = 0 \quad (11)$$

It could equally well be argued that Equations (9) and (10) can be combined with one equation⁷ of the rectifying section, for example, Equation (7), resulting in

$$\begin{vmatrix} A'_2 - A'_1\phi'_{21}^m & B'_2 - B'_1\phi'_{21}^m & C'_2 - C'_1\phi'_{21}^m \\ A'_3 - A'_2\phi'_{32}^m & B'_3 - B'_2\phi'_{32}^m & C'_3 - C'_2\phi'_{32}^m \\ A_1 - A_2\phi_{21}^n & B_1 - B_2\phi_{21}^n & C_1 - C_2\phi_{21}^n \end{vmatrix} = 0 \quad (12)$$

As a matter of fact equations containing ϕ_1 and ϕ_2 , and ϕ'_1 and ϕ'_3 can also be written, and therefore many more combinations of equations can be used to form determinants such as (11) and (12), but only two determinants are independent. These two determinants are merely equations containing the two unknowns, stripping and rectifying plates, as exponents. Many approaches are available to the trial-and-error calculation for these plates, but equations such as (11) and (12), where one determinant is formed from two stripping section equations and the other determinant from two rectifying section equations, have been found easiest to use. To start the calculation, a value of n is assumed and the corresponding value of m can be solved for without a trial-and-error calculation by Equation (11). Substituting this value of m in Equation (12), in turn a value of n is calculated. This process, or its reverse, is repeated until the assumed and recalculated value of n , or in the reverse case m , agree.

The following example of a ternary system should clarify the general procedure. Recovery fraction is denoted by the symbol $/v$.

Illustration 1

$$(X_A)_F = .2 \quad a_A = 2.5 \quad /A = .86$$

$$(X_B)_F = .4 \quad a_B = 2 \quad /B = .7$$

$$(X_C)_F = .4 \quad a_C = 1 \quad /C = .3$$

$$L = .15$$

Saturated Liquid Feed.

With $/A = .86$, $V = .722$

Equations (1) and (2) become numerically equal, respectively, to:

$$\begin{aligned} .722 &= \frac{(2.5)(.2)(.86)}{2.5 - \phi} \\ &+ \frac{(2)(.4)(.7)}{2 - \phi} \\ &+ \frac{(1)(.4)(.3)}{1 - \phi} \\ - .722 &= \frac{(2.5)(.2)(.14)}{2.5 - \phi'} \\ &+ \frac{2(.4)(.3)}{2 - \phi'} \\ &+ \frac{(1)(.4)(.7)}{1 - \phi'} \end{aligned}$$

$$\begin{aligned} (.A'_3 - A'_2\phi'_{32}^m)(40.2) \\ + (B'_3 - B'_2\phi'_{32}^m)(65.4) \\ + (C'_3 - C'_2\phi'_{32}^m)(28.0) = 0 \quad (14) \end{aligned}$$

$$\begin{aligned} (.A'_3 - A'_1\phi'_{31}^m)(40.2) \\ + (B'_3 - B'_1\phi'_{31}^m)(65.4) \\ + (C'_3 - C'_1\phi'_{31}^m)(28.0) = 0 \quad (15) \end{aligned}$$

From these equations, the following ϕ and ϕ' values were calculated:

$$\begin{aligned} \phi_1 &= 2.329 \quad \phi_2 = 1.287 \quad \phi_3 = .347 \\ \phi'_1 &= 2.775 \quad \phi'_2 = 2.288 \quad \phi'_3 = 1.255 \end{aligned}$$

$$\begin{aligned} \phi'_{31}^m &= \frac{-269}{-854} \\ &= (.548)^m; m \text{ is negative} \end{aligned}$$

Since the assumed value of n is far from correct as shown by the divergence of the three m values, new values of n could next be assumed until the three answers lie closer together and thus the correct solution could be found. Alternately, continuing with one of the m values and recalculating values of n are the better procedures in general, since the trial and error converges on the true solution.

Thus:

$$\begin{vmatrix} 12.6 & -8.89 & 2.73 \\ .900 & 1.60 & -5.01 \\ A'_2 - A'_1\phi'_{21}^m & B'_2 - B'_1\phi'_{21}^m & C'_2 - C'_1\phi'_{21}^m \end{vmatrix} = 0 \quad (13)$$

or

$$(A'_2 - A'_1\phi'_{21}^m)(40.2) + (B'_2 - B'_1\phi'_{21}^m)(65.4) + (C'_2 - C'_1\phi'_{21}^m)(28.0) = 0 \quad (13)$$

In setting up a determinant such as (11) it does not matter which two of the three rectifying section equations are utilized; any combination of rectifying section equations forming the determinant will result in the same answer for m even if the assumed value of n is not actually the true solution. However, the choice of the stripping section equation in determinant (11) does have an effect on the answer obtained for m , and unless the true value of rectifying plates has been assumed, three different answers of m result depending on which of the three available stripping section equations has been selected. All three results have been solved in the example to serve as a check in the trial-and-error calculation.

In addition to Equation (13), then, the equations

$$\begin{aligned} (.A'_3 - A'_2\phi'_{32}^m)(40.2) \\ + (B'_3 - B'_2\phi'_{32}^m)(65.4) \\ + (C'_3 - C'_2\phi'_{32}^m)(28.0) = 0 \end{aligned}$$

and

$$\begin{aligned} (.A'_3 - A'_1\phi'_{31}^m)(40.2) \\ + (B'_3 - B'_1\phi'_{31}^m)(65.4) \\ + (C'_3 - C'_1\phi'_{31}^m)(28.0) = 0 \end{aligned}$$

are formed. Substituting all numerical values in equations (13), (14), and (15), m is solved for, respectively, as follows:

$$\phi'_{21}^m = \frac{-854}{-609} = (.824)^m; m = 10.2$$

$$\phi'_{32}^m = \frac{-269}{-609} = (.452)^m; m = 1.03$$

Selecting m equal to 10.2, then, n was calculated back with a determinant exemplified by Equation (12) and the three solutions obtained were:

$$\phi_{21}^n = \frac{66.4}{29.0}; n \text{ is negative}$$

$$\phi_{32}^n = \frac{29.0}{166}, n = 1.34$$

$$\phi_{31}^n = \frac{66.4}{166}, n = .482$$

Using n equal to 1.34, the m values calculated were:

$$\phi'_{21}^m = \frac{106}{395}, m = 6.85$$

$$\phi'_{32}^m = \frac{378}{106}, m = 9.41$$

$$\phi'_{31}^m = \frac{378}{395}, m = 8.78$$

m is approaching the correct solution, as a comparison of the three m values shows. It is now easy to see which value of m to pick to continue calculations. The choice falls on m equal to 6.85 since here no difficulty has been encountered with significant figures. Numbers such as .378 in the above calculations, the result of addition and subtraction of numbers a hundred times the size of .378, appear repeatedly in this type of calculation and since these relatively small numbers are likely in error they should be disregarded. Actually, in the above calculations more significant figures were carried than are shown, else the value of m determined by the last two equations would have been quite uncertain.

Further calculations back and forth are summarized below:

$$\begin{aligned}m &= 6.85, \quad n = 1.30, 1.37, 1.34 \\n &= 1.37, \quad m = 6.76, 6.74, 6.72 \\m &= 6.76, \quad n = 1.37, 1.36, 1.36\end{aligned}$$

Choice of the value of n or m to be used in any succeeding trial is largely a matter of judgment. In this example, the convergence was relatively slow, typical of "slippery" separations, and the best choice of m or n is important if it is desired to hold the number of trials back and forth to a minimum. In "tight" separations the convergence is much more rapid, and less care in the calculations is necessary.

More ternary systems have been solved in the same fashion. Using the system of Illustration 1, the recovery fraction of component A was varied within the limits possible. Resultant plate numbers are plotted against this recovery fraction in Figure 1, showing a minimum in the number of total plates at $/c = .825$, where $n = 2.00$ and $m = 3.34$. It will be seen from Figure 1 that the minimum point in total plates is well-defined, and that only a slight change in the recovery fraction of the diluent results in an easily established and definite change in plate requirements.

Since Illustration 1 constitutes a slippery separation, another system was solved, this time with a tight separation to determine the applicability of the method at the opposite extreme of separation specifications. In Illustration 2, a heavy diluent, component C , was selected rather than a light diluent as in Illustration 1, and plate numbers were calculated at several values of the recovery fraction of C .

Illustration 2

$$\begin{aligned}(X_A)_F &= A - a_A = 3 \quad /A = .98 \\(X_B)_F &= A - a_B = 1.5 \quad /B = .02 \\(x_C)_F &= 2 - a_C = 1 \quad C \text{ is variable} \\P &= 2\end{aligned}$$

Saturated liquid feed.

The recovery fraction of the diluent, component C , is plotted vs. the calculated plate numbers in Figure 2, showing total plates to be minimum at $/c = .00040$. At this point, $n = 8.7$ and $m = 8.0$. Again it will be seen that a minimum in the curve of total plates is well-established, although the minimum is broader in Illustration 2 than in Illustration 1. No difficulties were encountered in the calculations other than the obvious difficulty of working with the number of significant figures which must be carried to define the value of ϕ_3 .

It will be noted that in Illustration 2, the rectifying vapor flow rate was held

constant rather than the liquid flow rate as in Illustration 1. Actually, either may be held, the choice being completely arbitrary. In general it is slightly more convenient to hold the vapor rate constant.

From Figures 1 and 2, some conclusions can now be deduced about the limits imposed on the choice of the diluent recovery fraction. From Illustration 1, the limits appear to lie within the diluent recovery fraction at minimum reflux, $/A = .90$, and the recovery fraction at minimum plates, $/A = .801$. In Illustration 2, one limit lies above the recovery fraction at minimum reflux, $/c = 0$, which it, of course, must do, but the other limit, rather than lying below the recovery fraction at minimum plates, $/c = .000215$, lies considerably above this, somewhere in the region of $/c = .001$. The recovery fraction corresponding to minimum total plates, $/c = .00040$, also lies above the recovery fraction at minimum plates.

However, the knowledge of the exact location of these limits will be of value only occasionally, and in the general case a first choice of the diluent recovery fraction should be made somewhere between the limits set by the recovery fractions at minimum plates and minimum reflux. If the column is indeterminate under this choice, as was found with the stipulation of $/A = .81$ in Illustration 1, it will be obvious in which direction the recovery fraction should be adjusted. If the exact calculation of the limits is desirable, then this may be done by the method of the following section, assuming infinite plates in first one section and then the other, back calculating the corresponding diluent recovery fraction in each case.

In this section no systems of higher order than ternary systems have been solved, but the method presented is not restricted to ternary systems. In a four-component system, for example, three independent fourth-order determinants, developed analogously to Equations (11) and (12), can be set up. The fourth-recovery fraction is guessed at. The ϕ and ϕ' values are obtained, and again plates are solved for by trial-and-error calculation between two determinants. The third determinant is used to check the assumed fourth recovery fraction, and if the divergence between the assumed and calculated values is substantial, the calculations are repeated with the new value of the fourth recovery fraction until the divergence is as small as desired. This calculation procedure will be more fully understood after reading the next section, which employs essentially the same technique.

From the methods of calculation of this section, particular column solutions may be obtained for various set separa-

tions of three components. This applies equally well to systems containing a component lying between the keys in volatility, a "sandwich component," although for systems containing more than one such component, the calculations will most certainly be difficult. However, in practical work, the specification of minimum total plates is much more likely than the specification of a third component recovery fraction, and although the column solution for this more likely specification can be determined by the method of this section, the method of the following section is considerably easier to use.

Stipulation of Minimum Total Plates. Minimum total plates at a chosen reflux could be obtained through differentiation of the basic equations. For a ternary system with key components A and B , for example, this differentiation would be indicated by

$$\frac{d(n+m)}{(c/e)} = 0 \quad (16)$$

or

$$\frac{du}{d(c/e)} = -\frac{dm}{d(c/e)} \quad (17)$$

However, because n and m are only indirectly functions of the recovery fraction of component C , partial differentiation through many intermediate variables is necessary, so that a very involved equation of little practical use would express the condition of minimum total plates at a chosen reflux.

Obtaining the optimum total plates as in Illustrations 1 and 2 is too tedious in general, but looking for a different approach a new riddle is confronted, since, as the variables forbid knowing the products of multicomponent mixtures entirely, none of the ϕ and ϕ' values can be solved for exactly in Equations such as (1) and (2). Thus, at first glance, it appears that no start can even be made toward the solution for optimum plates without specifying a third or all recovery fractions. The answer to the riddle is apparent, however, from Illustration 2, the tight separation case, where the ϕ values are the solution of the following equation:

$$2 = \frac{(3)(.4)(.98)}{3 - \phi} + \frac{(1.5)(.4)(.02)}{1.5 - \phi} + \frac{(1)(d(x_C)_d)}{1 - \phi} \quad (18)$$

Although no exact value can be known for the amount of component C in the top product, if the split is tight and $d(x_C)_d$ is very small, the last term in Equation (18) must be negligible in comparison with the other two terms in the solutions of Equation (18) for ϕ_1 and ϕ_2 . Furthermore, if the recovery fraction of C is very small, the value of ϕ_3 is known with considerable ac-

curacy, except for use in the evaluation of the term C_3 , since ϕ_3 must be very nearly equal to a_c in order that C_3 times $d(x_c)_d$ will be large enough to make the sum of the three positive terms on the right hand side of Equation (18) equal to the vapor flow. Thus, if as a first assumption, $/v$ is set equal to zero, ϕ_3 becomes equal to one, and the approximate evaluation of $C_3 d(x_c)_d$ is permitted, as follows, even though the two individual terms are not known.

$$\begin{aligned} C_3 d(x_c)_d &= 2 - \frac{(3)(4)(.98)}{3-1} \\ &= \frac{(1.5)(4)(.02)}{1.5-1} \\ C_3 d(x_c)_d &= 1.30 \quad (19) \end{aligned}$$

Passing next to the stripping section, no trouble is encountered in solving for ϕ'_1 , ϕ'_2 , and ϕ'_3 since the amount of component C in the bottom product has been assumed to be equal to the amount in the feed. In the system of Illustration 2 it is apparent that the assumption that component C is wholly in the bottom product, that is, that $/C = 0$ is an excellent assumption, and although errors have been introduced in all ϕ and ϕ' values, it is certain that the errors are small. Thus the determinant, Equation (12), which utilizes only terms made up of ϕ_1 , ϕ_2 , ϕ'_1 , ϕ'_2 , and ϕ'_3 , can be set up, knowing all its terms with fair accuracy. This is, however, the only determinant which can be set up in which all the parts are accurately known, except for those determinants which can be formed from any other combination of two of the three stripping section equations. However, all these resulting determinants are algebraically equivalent, and any other independent determinant must involve the definitely unknown quantity, C_3 . Actually, only one determinant is desired, since a second determinant would permit only a solution as shown in the preceding section, that is, a unique set of stripping and rectifying plates. Having only one determinant available is less of a restriction in that for each value of m a value of n corresponds or vice versa, and each of these sets of values may be made a solution. The particular set desired is the one where m plus n is a minimum. In the illustrated example and whenever all ϕ' values are known, a value of m is assumed and Equation (12) or its algebraic equivalent is solved explicitly for n . The reason for this procedure is obvious, since if a value for n had been assumed, one would be forced to trial-and-error calculation for m .

Continuing with the system of Illustration 2, several values of m are assumed, the resulting n values obtained from Equation (12), and a graph

of plates in either of the sections vs. total plates is plotted, permitting the location of minimum total plates. To this particular optimum combination of stripping and rectifying plates belongs a certain value of $d(x_c)_d$, the evaluation of which constitutes the checking of the assumption that this concentration is such that the ϕ and ϕ' values used in Equation (12) were sufficiently correct. This value of $d(x_c)_d$ can be solved for if the corresponding value of C_3 can be obtained. Setting up, again, any determinant which contains the term C_3 , for example:

$$\begin{vmatrix} A'_2 - A'_1\phi'_{21}^m & B'_2 - B'_1\phi'_{21}^m & C'_2 - C'_1\phi'_{21}^m \\ A'_3 - A'_1\phi'_{31}^m & B'_3 - B'_1\phi'_{31}^m & C'_3 - C'_1\phi'_{31}^m \\ A_1 - A_3\phi_{31}^n & B_1 - B_3\phi_{31}^n & C_1 - C_3\phi_{31}^n \end{vmatrix} = 0 \quad (20)$$

allows the calculation of C_3 , since all other terms in such a determinant, including particular values of n and m , are known with a high degree of accuracy. A_3 and B_3 are obtained through the fact that ϕ_3 is essentially equal to a_c , or to one in Illustration 2.

Assuming values of m , values of n were found from Equation (12) to be:

| m | n | Total |
|------|-------|-------|
| 6.50 | 11.25 | 17.75 |
| 7.20 | 9.60 | 16.80 |
| 8.00 | 8.71 | 16.71 |
| 9.20 | 7.69 | 16.89 |

The graph, plotted as mentioned previously, showed $m = 8.00$, $n = 8.71$ to correspond to minimum total plates. Inserting these values in Equation (20) and solving for C_3 , a value of $C_3 = 17,700$ was obtained. $d(x_c)_d$ was then found to equal .0000784 and $/v$ to equal .000392. Figure 2 shows these values to be correct at minimum total plates within the accuracy of the plot. It is apparent, furthermore, that the assumed value of the recovery fraction of C equal to zero was correct within the number of significant figures carried in the calculation. Had this not been the case, the recovery fraction of C calculated above should have been taken as a second approximation and the calculation repeated until the assumed and recalculated values of $/v$ agreed. However, as the example shows, in any fairly tight split no sandwich component, recalculation will seldom be necessary.

The first assumption of the recovery fractions of the diluent components is not always as easy as in Illustration 2. In Illustration 1, the separation is so sloppy that an assumption of the recovery fraction of A equal to one or even an assumption of $/A = .89$ results in ϕ and ϕ' values such that the recalculated recovery fraction of A is negative. Recalculated value of the recovery fraction always is overcorrected, re-

sulting in Illustration 1 in extreme overcorrection unless the recovery fraction is reasonably close to the optimum value. In systems of the general type of Illustration 1, the better method of solution is probably the method of the first section, although the method of this section can be used if various recovery fractions are assumed until the assumed and recalculated values of the recovery fraction are close enough for a converging series to the true recovery fraction to be established. Fortunately such sloppy separations are seldom en-

countered in practical work where the assumptions of constant relative volatility and constant flows are justified.

A more serious failure of the method of this section occurs in systems containing a sandwich component. There also the initial assumption of the recovery fraction of the sandwich component, somewhere between the recovery fractions of the key components, is very difficult, and again the procedure of the first section must be resorted to.

However, to erase the impression that the separation of the keys must be as tight as that in Illustration 2 to allow use of the method of this section, effectively, the following example, which is more representative of separations ordinarily encountered though still quite sloppy, is presented.

Illustration 3

$$\begin{aligned} (X_A)_F &= A \quad a_A = 3 \quad /_A = .85 \\ (X_B)_F &= A \quad a_B = 1.5 \quad /_B = .15 \\ (X_C)_F &= 2 \quad a_C = 1 \end{aligned}$$

$$l' = 1.2$$

Saturated Liquid Feed.

As a first assumption, $/v$ was assumed to be zero.

ϕ_1 , ϕ_2 , ϕ'_1 , ϕ'_2 , and ϕ'_3 were obtained.

Under this assumption, $\phi_3 = a_c$, and so C_3 is unknown. The determinant set up gave for the assumed m values the following values of n :

| m | n | Total Plates |
|------|------|--------------|
| 4.00 | 5.20 | 9.20 |
| 4.50 | 4.49 | 8.99 |
| 5.00 | 4.02 | 9.02 |
| 6.00 | 3.43 | 9.43 |

From the graph of these results, the values, $m = 4.70$ and $n = 4.28$ were found to correspond to minimum total plates, 8.98. The recovery fraction of component C back calculated with these plate numbers was .0327.

The value of $/e = .0327$ was then assumed and the process repeated. This calculation gave the following results:

| <i>m</i> | <i>n</i> | Total Plates |
|----------|----------|--------------|
| 4.00 | 5.18 | 9.18 |
| 4.50 | 4.49 | 8.99 |
| 5.00 | 4.04 | 9.04 |

It is apparent that the values of the plate numbers have been shifted only very slightly by this second calculation. From a plot of the results the point of minimum total plates was found to occur at $m = 4.65$ and $n = 4.33$, again a total of 8.98. The relative magnitude of the two sections has changed, but without extreme care such a shift is difficult to determine with surety since the minimum in the curve of total plates is quite flat. The back calculated recovery fraction of component C was now found to be .0276, a value considerably different from the value of the first trial, mainly due to the shift in relative magnitudes of plates in the two sections. However, even this change will have little effect on any subsequent ϕ or ϕ' values except the value of ϕ_3 .

If a third trial is then made employing the new value of $/e = .0276$, no change will be found in plate numbers due to the negligible effect of this new value on the ϕ and ϕ' values used in the determinant to determine plates. However it is quite possible to insert the newly calculated value of ϕ_3 in the second determinant and reevaluate $/e$. When this was done, a third value of $/e$ was obtained equal to .0282. Employing this value in still another recalculation of $/e$, a fourth value of $/e = .0282$, identical to the third value, was obtained.

Illustration 3 demonstrates that the calculation method proposed can be tried to obtain column solutions of any desired accuracy. However, it is also apparent that for most practical work only one calculation will be required. With systems containing large amounts of diluent components and/or diluent components close to the key in volatility, a second and even more trials may be necessary, but such systems will become easily recognizable after a few calculations with the method, and for the most part the calculator will be able to judge when the solution is as accurate as is desired.

Thus far again, the solution of this section has been presented only for ternary systems. However, systems of any number of components may be calculated in exactly the same manner. A single determinant, of the same order as the number of components in the feed, and in which all terms but n and m are known with reasonable accuracy,

can always be constructed. Back calculation of the recovery fractions of the diluent components requires for each of these components the solution of one additional determinant. As a further illustration, considering a four-component system of *A*, *B*, *C*, and *D*, six independent equations of the type of Equations (3) and (4) may be written. If *B* and *C* are the key components, the assumption is made that the recovery fraction of *A* is equal to one, and the recovery fraction of *D* is equal to zero. Under these assumptions equations containing P'_1 and D_4 are not usable in the determinant to be solved for *n* and *m*. Four independent equations then remain for the construction of this determinant. Once *n* and *m* are determined, back calculation of the recovery fractions of *A* and *D* are made by solving two determinants containing A'_1 and D'_4 respectively.

It will be noted that in systems where the key components lie intermediate between diluent components in the list of components, the solution for *m* or *n* requires a trial-and-error procedure. However, this trial and error has been found to be extremely rapid. In systems where the keys are at one end of the list of components, no trial and error are necessary.

The column solution presented is rapid unless the number of components is large and a determinant of high order must be solved. In such cases considerable time must also be spent in determining the various values of ϕ and ϕ' . Fortunately, in most cases, the solution will be sufficiently exact in the first trial that no retrials are necessary. However, the time necessary is generally sufficiently large that any reduction in the complexity of the equations or in the number of ϕ or ϕ' values which must be obtained will result in material savings in time. A second paper will present an approximate solution for plates, of almost equal accuracy to the solution of this paper, and one which requires essentially the same amount of time no matter what the number of components.

Notation

- b* = moles of bottom product, based on one mole of feed
- d* = moles of top product, based on one mole of feed
- d*' = differential operator
- m* = number of plates in stripping section, including reboiler but not feed plate
- n* = number of plates in rectifying section, including feed plate
- x_i* = mole fraction of a component *i* in a liquid; without further subscript, the

mole fraction of component *i* in liquid on feed plate, with further subscript outside parentheses, the mole fraction of component *i* in the liquid indicated by subscript

A, *B*, *C*, etc., without subscript = letters identifying components, of which *A* is the lightest in volatility, *B* the next lightest, etc.

F = moles of feed, equal to one for convenience

L = rectifying section liquid flow, moles/mole of feed

L' = stripping section liquid flow, moles/mole of feed

L' = rectifying section vapor flow, moles/mole of feed

L'' = stripping section vapor flow, moles/mole of feed

X_i = mole fraction of component *i* in total feed

f_i = recovery fraction of component *i* in top product = $\frac{d(x_i)}{F(X_i)F}$

a_i = relative volatility of component *i*; all relative volatilities to be based on same component

φ₁, φ₂, etc. = a set of rectifying section parameters; *φ₁* is the largest, *φ₂* next largest, etc.

φ'₁, φ'₂, etc. = a set of stripping section parameters; *φ'₁* is the largest, *φ'₂* next largest, etc.

A₁ = abbreviation for $\frac{a_4}{a_4 - \phi_1}$

as $B'^1 = \frac{a_H}{a_H - \phi'_1}$, etc.

φ₂₃ = abbreviation for $\frac{\phi_2}{\phi_3}$, as

$\phi'^{23} = \frac{\phi'^2}{\phi'^3}$, etc.

SUBSCRIPTS:

A, B, C, etc. = components *A, B, C*, etc.

i = any general component

1, 2, 3, etc. = relative magnitude of ϕ or ϕ' values or indicate terms used in abbreviations such as *A₁*

b outside parentheses refers to bottom product

t outside parentheses refers to top product

f outside parentheses refers to feed

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• NEWS SECTION •

PROFESSIONAL PROBLEMS DOMINATE ANNUAL MEETING

WHILE technical papers and meetings, and a full-rounded program telling of chemical engineering achievement occupied most of the time at the recent A.I.Ch.E. annual meeting in Pittsburgh, the prime business of the week was strictly the problems of professionalism. An intense two and a half hour panel discussion on licensing of engineers held Sunday afternoon focused attention on one requirement of a professional engineer, and the next day, at the first of what was to be a three-session business meeting, the proponents and opponents of several constitutional amendments proposed by the Institute Council, debated on another professional matter—membership qualifications in the Institute.

Only a minimum of other business was attempted at the business session. President Curtis early turned over the meeting to Warren L. McCabe, Chairman of the Constitution and By-laws Committee who understood the detailed and difficult task of explaining the proposed amendments to the membership. Opposition to one change developed quickly and as the morning discussion came to a close, voting showed that the Council proposal on active membership was unacceptable to the majority in attendance. Specifically, incorporation in active membership qualifications of examples of the broad fields of application of chemical engineering was the stumbling block. Council, while the business meeting was recessed, revised proposed amendments in accordance with the wishes expressed at the morning session. However, other important proposals affecting membership originally proposed by the council resolution were welcomed by those at the business meeting. These were the creating of a student grade of membership, and an automatic transfer to associate membership of all junior members who have not transferred to active membership by



W. H. McAdams, M.I.T., presenting "First Institute Lecture."

the time they are 35 years of age. Junior membership was further modified by elimination of the stipulation that the candidate be "engaged in engineering work."

Associate membership changes were approved also. If the new amendments are accepted by the members in their voting, this classification will be

opened to those who are "engaged in an activity and possess scientific attainments or practical experience which qualify them to cooperate with engineers in the advancement of chemical engineering knowledge and practice."⁴

That this will open up the membership of the Institute to many who do not now qualify leaves no doubt, though members of council were firm in their avowal that the professional grade, active membership would not be and is not devalued by any of the proposed amendments.

The recessed morning business meeting reconvened late Monday afternoon for a continuation of the task of thrashing out acceptable revisions. It first developed in the afternoon voting that elimination of the ballot of new members was agreeable, provided that the list of applicants approved by the committee on admissions was published in *Chemical Engineering Progress*. This gives the members an opportunity to vote on all candidates. This was a compromise between the present method of letter ballots to every active member, and the proposal of council that the ballot be eliminated entirely.

(Continued on page 10)



Oscar v. d. Luft, Honorary Chairman, Pittsburgh Meeting, and G. A. Webb, General Meeting Chairman, Koppers Co., Inc.; James Coull, University of Pittsburgh; B. H. Sage, California Institute of Tech.; W. C. Edmister, Carnegie Institute of Tech., and E. R. Gilliland, M.I.T., speakers at Symposium on Phase Equilibria.

THE ENGINEER'S PLACE IN SOCIETY

MOTT Souders, Jr.

Shell Development Company, San Francisco, California

In order to decide the place of the engineer in society, it may be well to devote some time to a consideration of what the engineer does, how he goes about it, and what essential character of mind he must have to accomplish his works. In the first place, the engineer is a builder who draws information from many sources, weighs the data, and resolves their conflicts in such a way as to find the optimum compromise among diverse requirements. He accepts full responsibility for the end-product of research and development, which is a plant that will operate safely, efficiently, and economically. In so doing he guarantees not only his own work, but also that of the scientist and technologist whose data he applies. In this he must be highly critical of the information supplied him and must make sure that he allows for inevitable error. The engineer knows from personal experience that man's understanding of his environment is tentative, fragmentary, and inexact. For instance, the oldest chemical engineering process, the manufacture of salt by solar evaporation of sea water, has been practiced for thousands of years and yet a truly scientific explanation of the process is not known. Over the years, we have accumulated, of course, many empirical facts on the mutual solubilities of some components of sea water, but we still don't know exactly why salt has a positive and gypsum a negative temperature coefficient of solubility, or even why salt is more soluble than lime. And even our empirical data can't always be trusted since the solubility of the salts is affected by the presence of organic matter in the sea water. The engineer today must literally take his solubility data "with a grain of salt."

Hence the engineer must so design his plant as to allow for human fallibility, to provide for error in the interpretation of nature as well as error of ignor-

... this year's recipient of the Professional Progress Award in Chemical Engineering implies that the engineer worth his salt is eminently practical yet he is idealistic . . . he must be realistic yet his imagination must be given play in confronting new problems . . . social issues should command his attention now . . .

ance and accident. The process engineer allows for errors in fact and theory by estimating the probable range of error and providing a compensating safety factor. The greater the uncertainty the greater must be the safety factor, and if there are two plausible scientific theories which cannot be reconciled by the use of a suitable safety factor, the engineer must reject both and rely entirely on pragmatic tests in the pilot plant or elsewhere. He dare not choose one of the theories and hope for the best.

The engineer is notably practical. He views with suspicion all abstractions, theories and doctrines. This strain of practicality is regarded by many scientists as lamentable, but it is not without merit. The engineer must be realistic since his experiments are socially costly. A scientist can afford to be a romanticist; his failures do not cost much and he can afford to try again and again. If an engineer builds a twenty-million-

dollar plant which fails because it is unsafe or unoperable, it is a general disaster leading to bankruptcy for the employer, death, injury, and unemployment for the workers, and ostracism for the engineer. On the other hand, if the scientist undertakes an experiment which fails, he loses little more than his wasted time and even the failure adds to his education and makes him a better scientist. The heavy responsibility that the engineer bears naturally makes him conservative in his evaluations and restrained in his promises.



DR. MOTT Souders, Jr., head of the chemical engineering research section of Shell Development Co., San Francisco, and winner of Professional Progress Award in Chemical Engineering for 1949, has been

associated with Shell since 1937. He was formerly associated with Smith Engineering Co., Kansas City, Mo., and with Yale University. He has published more than 60 technical papers and holds some 20 patents.

His conservatism, however, is that of the calculated risk rather than a conservatism of inaction and opposition. Despite his practicality, the engineer is ever confronted with new problems which require him to seek new and better means for solving them. He must therefore be receptive to novel ideas, although careful in his judgments of them. Finally, the engineer is a master of the art of compromise. His work is a succession of choices among alternatives both economic and technical from among which he must select the optimum. In economics he has learned that values are relative rather than absolute; that the amount of heat to be saved or wasted must represent a compromise between the cost of exchanger surface and the value of the fuel burned. In technical matters he is faced with a succession of compromises among mutually conflicting requirements. For instance, one of his conditions may vary with the diameter of the apparatus, while another condition varies as the square of the diameter. These conflicts he must resolve by a compromise that is acceptable to both requirements. In the final analy-

sts, engineering is the finding of a working compromise among requirements that are mutually inconsistent.

Let us turn now to a consideration of the social climate in which we all live. The present may well be called the age of anxiety. The buoyant optimism of the nineteenth century, lifted to the heights by the promise of science triumphant, hand in hand with political democracy, has collapsed before our eyes. Today anxiety is the vinegar in every dish and the lump in every bed. In the social sphere we face the rise and spread of an amoral communism which denies the dignity and integrity of man, which exalts the state and makes of men only the means to an end. In both physics and philosophy the meaning of the uncertainty principle makes us doubt that knowledge can be expanded without limit. In both science and sociology, we are acutely aware of the second law of thermodynamics, which clearly implies that the universe is running down. In technology we foresee the exhaustion of our low entropy reserves of fuels, metals and fertilizers. In political economy we ride a ground swell of programs and policies which can lead only to the dissipation of our capital, to the eating of our seed corn before it can be planted. In every area of mind and matter we see entropy rising at an appalling rate.

In the domestic economy we face a series of conflicting aims. How can we broaden the distribution of wealth without destroying the incentive for production? How can we raise wages without increasing prices? How can we increase our security without losing our freedom? In the international sphere, the overwhelming problem is how to resolve conflicting national aspirations without resort to war. Everywhere we are confronted with problems that are mutually inconsistent, and it is evident that they can be resolved only by finding a working compromise.

This is indeed a dismal outlook—for anyone who is not an engineer. To the engineer, the outlook is by no means hopeless. In fact, the conditions of the problem are vaguely familiar to every process engineer and seem to require the methods and discipline of engineering.

These are all positive questions, questions of method. Their essence is "how shall we do it?", not "what's the use of trying." The aspirations of mankind, the idea of social justice and the ideal of peace and plenty are not to be denied. The core of the problem is "what is the best way to go about?" And that is the typical engineering assignment. When the boss asks us to design a process for separating those tenacious Siamese Twins, meta and para xylene, we don't

disparingly tell him that he is an impractical idealist. Instead we review the available means and when necessary invent one or two new ones. And then we tell him what it will cost so that he can decide whether it is worth while. By this procedure, the engineer over the last century has exerted a profound influence upon his physical environment.

The engineer appears to be equally well situated to influence his social environment. He has greater power than he realizes: he has the confidence of the general public. His is a position of influence because the works he offers to society, unconfined by doctrine and dogma, pass the pragmatic test; they operate as promised.

Engineer and Facts

Moreover the engineer is a judge rather than an advocate. He has the habit of analyzing. He listens to partisans of this theory and that while always trying to face the facts. He is loath to align himself with either extreme in the struggles over social policies. Nevertheless the engineer works for things rather than against them. He is the builder of the new rather than the conservator of the old.

Finally, the engineer has mastered the art of compromise. If we solve our social problems, it will be through compromise among requirements that are mutually inconsistent.

Whatever the qualifications of engineers as a group, the measure of their social effectiveness lies ultimately in the efforts of individual engineers. "But," you ask, "what can the individual do about it?" I sincerely believe there is a great deal he can do about it, and I should like to suggest a program to you.

First, I think it behooves each of us to examine the important social issues in the same manner as we would an engineering proposal. What are the facts? What evidence supports the theories, however plausible? What can be done to test it on a small scale before applying it on a large scale? What will it cost and what will it produce? What are the by-products and how will we handle them? What allowances are proposed for inevitable error? If it doesn't work, will the cost to society be excessive?

Second, having arrived at our own considered opinion, we should make an effort, even at the sacrifice of some of our own time and comfort, to explain to others the basis of our judgment. We should speak before civic groups and write letters to the editor. Above all, we should discuss the issues with our neighbors and acquaintances whom we have in all walks of life. And we should listen honestly to those who hold con-

trary views so that we earn the courtesy of being heard in turn. As engineers we shall naturally avoid dogmatism and emotion in presenting our side of the case, and show the willingness to compromise where compromise is essential to a working arrangement.

As Alan Barth has so clearly explained:

"The democratic process is one in which the antidote for poisonous ideas is healthy ones; in which the sifting of truth from falsehood, of wisdom from folly, must be left to the good sense of the people. It is not an infallible process. But it is the only process by which the just powers of government can be derived from the consent of the governed."

The turbulence of the American system, the pushing and hauling, the checks and balances, the reliance on persuasion rather than coercion, the denial of absolute power even to the majority, all tend to make it seem cumbersome, lethargic—even inefficient. It may be all these; but it works. For all its defects, it is well adapted to the character and circumstances of the American people.

A critic might complain with some logic that in the long period of human gestation and the painful hazards of childbirth, nature had devised a senselessly difficult arrangement for the perpetuation of the human species. There is a good deal of evidence, however, that the difficulties serve extremely useful purposes. They help to shape an emotional attitude on the part of parents to offspring which has made the family so enduring an institution.

Equally, the delays and impediments of the democratic process contribute significantly to a sense of national unity. They have a powerfully cohesive influence. For when the process has been fulfilled, it affords a widespread feeling of participation in the decisions reached. The minority, if not persuaded as to the wisdom of the majority, has at least had a chance to speak out, and knows that it can go on in conformity with the rules of the game, still hoping to transform itself into a majority" (1).

Engineer and Statesman

Earlier in this discussion, we defined engineering as the finding of a working compromise among requirements that are mutually inconsistent. This definition seems to be equally valid as a definition of statesmanship. If we foster the use of the engineering method in the analysis and discussion of social problems, each in his own community and in his own way, we can all be statesmen in a world that is crying out for statesmanship.

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Award address given by Dr. Souders at the A.I.Ch.E. Meeting in Pittsburgh, Dec. 4-7, 1949.

ANNUAL MEETING

(Continued from page 7)



Prize winners after presentation at Awards Banquet. W. H. McAdams, William H. Walker award, Mott Souders, Professional Progress Award, and Edward Scheibel, Junior Award.

Another change in the council amendments was indicated when the proposal on the committee on admissions was opened for discussion. In effect the proposed amendment eliminated from the Constitution the specific number of men on the Committee. Though the vote was almost even, Council at still another session, revised the proposal so that the original number on the committee, fifteen, still stands in the revision. The third and final business session was held the following day, again late in the afternoon. All proposals of Council, including amendments revised in the light of the meeting discussion were distributed as a mimeographed sheet. After a short discussion those attending the meeting voted to "go on record as approving the proposed amendments."

Members of Council expressed themselves as well pleased with the revisions. The interest shown in the amendments at the meeting was expressed by President Curtis as "great for the Institute" and that Council had tried to "incorporate as many suggestions as possible

in the new draft."

As provided in the Constitution, the amendments and a ballot will now be sent to the members by the Secretary for action.

—
C. E. T. —
C. E. T. —

W. H. McAdams receiving William H. Walker Award from F. J. Curtis, President, A.I.Ch.E.; T. K. Sherwood, M.I.T., Chairman Institute's Awards Committee in center.



TECHNICAL SESSIONS

Reported by R. A. Benzaquin

FEATURING three symposia and two panel discussions, the technical program at Pittsburgh contained more than 50 separate presentations. The symposia were on atomic energy, industrial waste disposal and phase equilibria while the panel discussions were concerned with professional licensing of engineers and the training of young engineers within industry.

The atomic energy symposium was the first one on this subject to be held by the Institute despite the tremendous contributions made by chemical engineers to the dramatic development of this nation's atomic energy program. Classification of information has, of course, been a deterrent in the publication or presentation of the greater part of this work.

Again the importance of the chemical engineer in the atomic energy program was emphasized during the symposium in the announcement of the appointment of a leading chemical engineer as head of the engineering division of the Atomic Energy Commission, Dr. George Granger Brown, head, department of chemical engineering, University of Michigan. The announcement was made by Dr. Lawrence R. Hafstad, director of reactor development for the A.E.C. (See *Announcement*, page 41, *Personalia*, this issue.)



J. D. Fennebresque, Celanese Corp., presenting Professional Progress Award to Mott Souders, Shell Development Co. F. J. Curtis, President, A.I.Ch.E., at right.



D. L. Katz, Chairman, Student Chapters Committee, presenting second prize of the A. McLaren White Award to Irving Begelman of Cooper Union. Left to right, W. E. Henderson, University of Illinois and first prize winner; W. H. McAdams, M.I.T.; W. L. McCabe, President-elect, A.I.Ch.E.; F. J. Curtis, President, A.I.Ch.E.; Mott Souders, Shell Development Co.

"Current Status and Problems of the Atomic Energy Commission's Reactor Development Program," was the opening paper of this symposium and was presented by L. R. Hafstad of the Atomic Energy Commission. The current program of reactor development, Dr. Hafstad said, is toward the construction of four different types of reactor which will serve essentially as demonstration units and as prototypes of future efforts. Any reactor development program, he emphasized, must be one-of-long range because of the immense number of factors which must be taken into account. The choice of the four different types for current study was arrived at only after lengthy consideration of the many possibilities. Among the four types, one will be built as a marine propulsion unit. Another reactor will be used to investigate the feasibilities of "breeder" operation in which fissionable material is produced by the reactor in greater quantity than



W. T. Dixon, Chairman, sub-committee on heat transfer; this is a sub-committee of Committee on Testing Techniques and Equipment Performance Standards of which T. H. Chilton, (right), Du Pont Co., is Chairman.

is originally supplied as fuel.

Walter H. Zinn, director, Argonne National Laboratory, outlined some of the critical factors involved in nuclear reactor design, using as illustrative material, data on the heavy water—uranium oxide reactor which was completed not long ago in France and is being used for experimental purposes. His paper entitled, "Some Basic Considerations in the Design of a Nuclear Reactor," discussed such aspects as critical size, choice of moderators, possible methods of cooling, power level, materials of construction, etc. All materials of construction must be considered in relation to their behavior in a unique environment—one of intense nuclear bombardment, he reported. Two other

papers, "Radioisotopes" and "Chemical Problems in Atomic Energy" were presented by L. B. Emlet, Oak Ridge National Laboratory, and Stephen Lawroski, Argonne National Laboratory, respectively. John R. Huffman, Argonne National Laboratory, presided over the symposium and was responsible for its organization.

The Institute's Committee on Industrial Waste Disposal of which R. D. Hoak, Mellon Institute, is chairman, gave evidence of its activity in the presentation of a ten-paper industrial waste symposium extending over two technical sessions. Charles E. Renn, Johns Hopkins University, related how the physiological and biochemical response of fish, which were subjected to environments polluted by various chemicals found in industrial wastes, were



J. C. Warner, President-elect Carnegie Institute of Tech., speaking at President's Luncheon. A. W. White, University of Michigan, P. J. Curtis, President, A.I.Ch.E. 1949, and E. R. Weidlein, President, A.I.Ch.E., 1927 and 1928.

Charleston plant on the Kanawha River. The problem of stream pollution, he said, becomes acute in this river at con-



Members, panel discussion on "Training in Industry of Young Engineers." K. H. McEachron, Jr., General Electric Co.; P. D. V. Manning, discussion leader, International Minerals & Chemicals Corp., and A. J. Johnson, Shell Development Co. Waste Disposal Symposium. R. D. Hoak, Mellon Institute, presiding, and Charles E. Renn, John Hopkins University, at microphone.

used as a criterion of water fitness. Although the fish tended to avoid certain conditions and were able to detect minute amounts of some materials, they were unresponsive to larger concentrations of several extremely toxic materials. Mr. Renn's paper was entitled, "Physiological Tests of Water Quality and Treated Wastes." H. D. Lyons gave a comprehensive case study of the problem faced by the Carbide & Carbon Chemicals Corp. relating to their South

ditions of low flow which occurs twice a year. At that time the total industrial use of water is about one and one-half times the total river flow. Although most of this usage is for cooling purposes and is returned uncontaminated to the river, the heating of the water decreases the oxygen in solution with the result that oxidizable wastes are not decomposed. The Carbon and Carbide program of waste control is now in its fifteenth year, and Mr. Lyons reported



Speakers, Atomic Energy Symposium. (Above) L. R. Hafstead, Atomic Energy Commission, and J. R. Huffman, Argonne National Lab. (Below) L. B. Emlet, Oak Ridge National Lab., and Stephen Lawroski, Argonne National Lab.



B. W. Gamson, Great Lakes Carbon Corp.; W. A. Selke, Yale University; R. C. Werner, Mine Safety Appliances Co., and W. H. Zinn, Argonne National Lab., speakers at technical sessions.



C. D. Helm, Mellon Institute, Chairman, Pittsburgh Committee on Hotel, Housing, Information and Hospitality; C. C. Long, Chairman, Pittsburgh Executive Committee, St. Joseph Lead Co.; C. J. Sindlinger, Mellon Institute, and J. K. Rice, Cyrus William Rice Co., both members, Registration Committee.



Members, Pittsburgh Public Relations Committee: H. L. Kellner, Co-Chairman, Gulf Oil Co.; E. P. Partridge, Chairman, Hall Laboratories, Inc., and H. B. Keck, Pittsburgh Consolidation Coal Co.

that the river which originally did not start to recover its oxygen balance even 25 miles below the plant, under conditions of low flow is now beginning recovery less than two miles downstream.

water treatment when the other two are insufficient. E. A. Pearson and Clair N. Sawyer discussed waste disposal problems in the beet sugar industry and the laboratory studies made by them in



J. Healy, Jr., Director, A.I.Ch.E., Monsanto Chemical Co.; C. R. DeLong, Treasurer, A.I.Ch.E., Consulting Chemical Engineer, and Hugh F. Beegly, member, Public Relations Committee, Jones & Laughlin Steel Co.

This result has been achieved, he said, by three approaches (1) modification of operation to eliminate or reduce wastes, (2) separation of wastes for by-product use or separate disposal, (3) use of

working out a satisfactory solution to these problems. "Treatment of Wastes Resulting from Tank Car Cleaning Operations" was the title of the paper presented by G. Gutzeit, General Amer-

ican Transportation Co. The wastes from such operation, he said, are unusually diverse in character. An interesting method was eventually worked out for the disposal of these wastes in which they were absorbed on finely ground coal which was subsequently removed from suspension by froth flotation. This coal can then be mixed with additional coal and fired under boilers.

W. C. Edmister, Carnegie Institute of Technology, lead the discussion in the symposia on phase equilibria which was held on Wednesday morning. Five papers were presented all contributing to the chemical engineers' need of better ways to evaluate accurately the physical properties of various materials. G. B. Webb, L. C. Rubin and Leo Friend, M. W. Kellogg Co., reported on "Liquid Vapor Equilibria in Light Hydrocarbon Mixtures." "Some Methods of Experimental Determination of Vapor-Liquid Equilibria" was the title of a paper by B. H. Sage and H. H. Reamer of California Institute of Technology. E. R. Gilliland's paper was concerned with the fugacity of vapor mixtures. M. J. Rzasa, J. B. Opfell and E. D. Glass of Stanolind Oil and Gas Co. presented a paper concerned with the critical properties and equilibrium constants for complex hydrocarbon systems. "Development of Isothermal and Isobaric Equations for Vapor-Liquid Equilibrium in Non-Ideal Systems," by James Coul and Kuo-tsung Yu, University of Pennsylvania, was the concluding paper.

John M. Weiss, chemical engineering consultant and chairman of the Institute's Committee on Professional Legislation was moderator at the panel discussion entitled "Professional Licensing of Engineers." Members of the panel were E. A. Holbrook, University of Pittsburgh, J. F. Fairman, Consolidated Edison Company of New York and T. K. Legare, National Council of State Boards of Engineering Examiners. Dr. Weiss, in his introductory remarks, reported the results of a poll of members

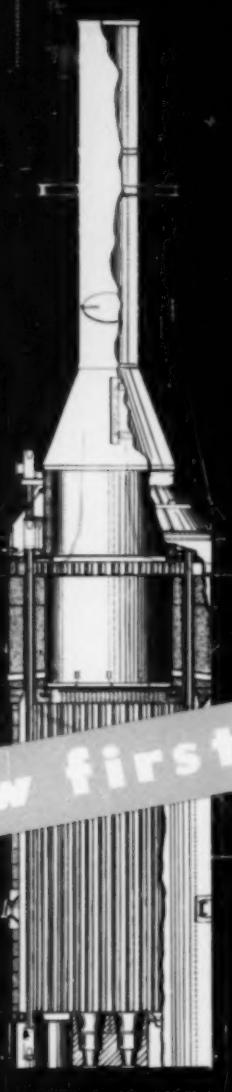
(Continued on page 24)

AWARDS FOR PAPER PRESENTATIONS



D. L. Katz, University of Michigan (extreme left), and W. H. Linton, Jr., M.I.T. (extreme right), were awarded first place for the presentation of papers at the recent A.I.Ch.E. Pittsburgh meeting. The winners were chosen by a group of judges under the direction of Walter E. Lobo of The M. W. Kellogg Co.—Dr. Katz, for "Effect of Vapor Agitation on Boiling Coefficients for Freon-12," by D. B. Robinson and D. L. Katz; Mr. Linton for "Mass Transfer from Solid Shapes to Water in Streamline and Turbulent Flow," by W. H. Linton, Jr., and T. K. Sherwood. Sol Weller (middle) won honorable mention for "Engineering Aspects of the Separation of Gases by Fractional Permeation Through Membranes," by Sol Weller and W. A. Steiner, Bureau of Mines.

Conferring of this award was started in 1949 to serve as an incentive to authors for the better presentation of technical papers at A.I.Ch.E. meetings.



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J. A. LEE

Southwestern Editor, Chemical Engineering

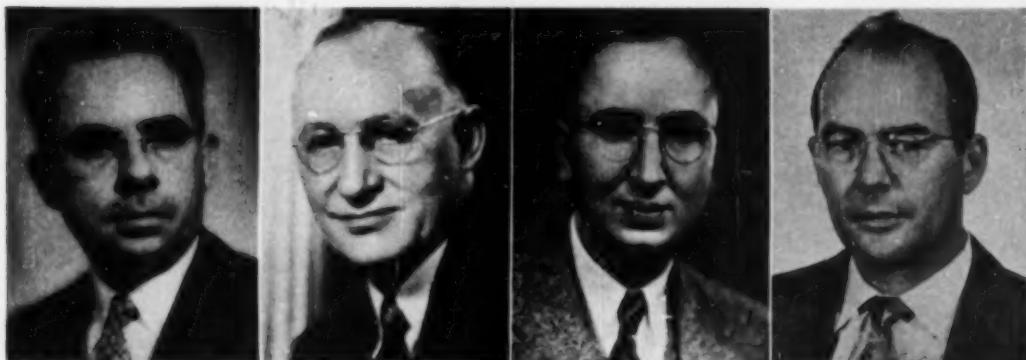
FAFULOUS Texas' industrial expansion attracted chemical engineers from all parts of the United States to Houston four years ago for a regional meeting of the American Institute of Chemical Engineers. Those engineers who return for the regional meeting Feb. 26-28 and March 1, 1950, at Houston's Rice Hotel will find a chemical industry that has doubled in size

in that amazingly brief period. At present the value of the plants is estimated at 700 million dollars. And this total does not include either the plant expansions now under way or the projected expansions.

Chemical plants that have been completed in the Southwest very recently or are under construction include: Aluminum Company of America, Port

Lavaca, metal; Carbide and Carbon Chemicals Corp., Texas City, vinyl resins; Carthage Hydrocol, Inc., synthetic gasoline, other petroleum products and chemicals; Commercial Solvents Corp., Sterlington, La., synthetic methanol; Corn Products Refining Co., Corpus Christi, dextrose, starch, oils, etc.; Diamond Alkali Co., Dallas, increased sod-

(Continued on page 17)



From left to right: J. L. Franklin, Chairman, South Texas Section; C. E. Lyon, Co-Chairman, Houston Meeting; K. A. Kobe and Mark Hopkins, Co-Chairmen, Program Committee.

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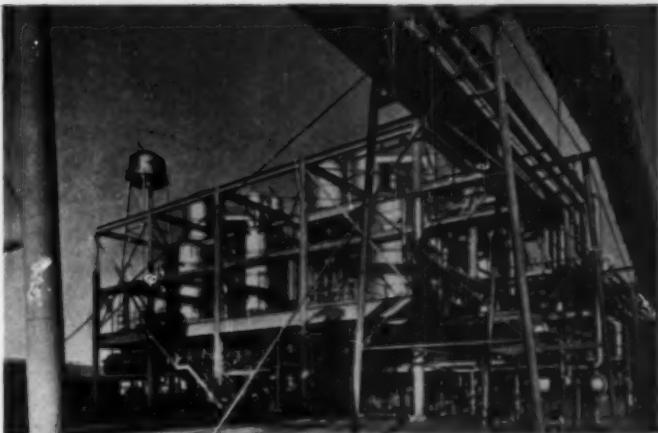
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ium silicate production; E. I. du Pont de Nemours & Co., Victoria, nylon salt intermediates; Esso Standard Oil Co., Baton Rouge, iso-octyl alcohol; Frontier Chemical Co., Denver City, Tex., increased caustic soda and chlorine production; Finney Chemical Corp., Houston, ammonium sulfate; Gulf Chemical Co., Houston, sodium and calcium phosphates; Jefferson Chemical Co., Port Neches, ethylene oxide, ethylene glycol and other petrochemicals; McCarthy Chemical Co., Winnie, acetaldehyde, methanol, formaldehyde; Rohm & Haas, Houston, raw materials for acrylic resins; Stanton Chemicals, Corpus Christi, aromatics and derivatives; Tennessee Eastman Corp., Longview, acetic acid, acetaldehyde and alcohols. Some of these plants as well as others in the Houston area will be visited by the visiting engineers.

Bull Sessions

One feature of the Institute's regional meeting will be informal discussion groups on Monday evening. R. L. Murray of Hooker Electrochemical Co., will head a discussion on training of chemical plant supervisors. William P. Schambra of Dow Chemical Co. will carry on a session on chemical plant surface protective coatings. S. D. Kirkpatrick, editor of *Chemical Engineering*,



Fifty Per Cent Caustic Soda Evaporators at Plant of Diamond Alkali, Houston.

has promised to start the discussion of What's New. Dr. Carl F. Prutton of Mathieson Chemical Co. will lead the discussion on the relations of the universities and industries in educating and training chemical plant technical personnel and J. Sharp Queener, general assistant manager of the Safety & Fire Protection division of E. I. du Pont de Nemours & Co., will conduct a discussion on chemical plant safety.

Ladies Program

A program has been arranged by Mrs.

Gaines N. Houston, head of the Ladies Committee. On Monday the group will be taken on a tour of the River Oaks residential area, followed by a coffee party at the home of Mrs. John Baird. In the afternoon the group will visit the Museum of Fine Arts. Later tea will be served at the Shamrock.

On Tuesday the ladies will have lunch and see a style show in the Empire Room at the Rice Hotel. In the evening they and their husbands will attend the banquet at the Rice.

Lunch on Wednesday will be at the Pine Forest Country Club. Those who wish may tour the antique shops in Houston.

Chemical Engineering Papers

In preparing the technical program for the meeting, particular attention has been given to making this as diversified as possible. Mark Hopkins and Kenneth A. Kobe co-chairmen of the program committee have attempted to develop the program so as to give ample space to materials which would demonstrate the diversity of interest in the region. This will explain the absence, at least, in the general paper session of strictly petroleum papers.

The tentative program calls for sessions on phase equilibrium, waste disposal, ultrasonics, alkali-chlorine and general subjects.

The phase equilibrium program is being handled by Dr. Wayne C. Edmister of Carnegie Institute of Technology. The symposium will consist of eight or nine papers occupying two sessions of the meeting.

Ultrasonics is under supervision of Dr. Dudley Thompson, department of chemical engineering, Virginia Poly-

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Aerial view of Sheffield Steel Plant in Houston. In the left foreground is the office building. Center foreground shows the buildings housing the open hearth furnaces and various rolling mills. In far background at left, are coke ovens which manufacture coke from Arkansas and Oklahoma coal and, right, the blast furnace which makes pig iron from East Texas ore.

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(Continued from page 17)

technic Institute, Blacksburg, Va. Two papers have been scheduled. Harold W. Danser, president of the Ultrasonics Corp., will present a paper which will consider in detail industrial applications to the chemical industry, and W. H. Jansen of General Electric will present a paper on methods and equipment required for generating ultrasonic energy.

Dr. Richard D. Hoak, of the Mellon Institute, working in the field of waste disposal has arranged for the presentation of two papers. Pollution Abatement and Industrial Water Management by Dr. Charles F. Hanck, will deal with methods of approach to the pollution abatement problem as well as methods for study and final solution and remedial measures to be taken. The second paper has been prepared by E. L. Demarest and W. D. Kohlins. This paper presents examples of the use of various equipment for the solution of specific waste disposal problems. From these specific instances summarized, equipment cost and an analysis of the economic aspect of the various types of waste disposal problems have been dealt with.

Alkali-Chlorine Industry

A symposium of six papers on the alkali-chlorine industry has been arranged by Dr. C. F. Prutton. This is a particularly significant subject for presentation and discussion in this area. D. O. Hubbard will discuss Optimum Operating Currents for Hooker Type S Cells. R. B. MacMullin has taken as a subject, By-products of Amalgam Type Chlorine Cells. W. L. Badger will describe Use of Dowtherm in Producing High Concentrations of Caustic. Robert M. Crawford has chosen Chlorination of Organics by HCl and Air. Charles P. Roberts will talk on the Copper Chloride Cell Process (Chlorine from HCl).

The symposium of general papers includes one by W. A. Pennington on The Evolution of a New Refrigerant. This paper will deal with the approach to a specific research problem and presents an example of the method of search along with the technical data and final results obtained. Some interesting thermodynamic tests were involved in this development work.

A paper dealing with diffusion rates in the extraction of porous solids will be presented by W. P. Armstrong. Tentative arrangements have been made for a paper on graphical solution of Steady-state countercurrent transfer problems by E. B. Fitch. Another paper will be on the centrifuge—its process potentials by C. M. Ambler. This paper will deal with fundamental principles which gov-

ern the use and application of centrifugals in the chemical process field. M. T. Howerton is slated for a paper on reaction kinetics. It will deal with reaction rates in the butane isobutene sulfuric acid system.

A paper on graphical solution for extractive and ternary distillation problems by J. M. Chambers is scheduled for the general session. This paper is the outgrowth of considerable work on extractive distillation, particularly as applied to the separation of solvents from complex mixtures formed as by-products in the Fischer-Tropsch process.

Student Session

Prof. W. W. Akers is organizing a student session. Students from Rice Institute, Texas University and Texas A & M College will take part. Their papers will deal with recent developments in either unit operations or chemical processes.

With regard to the student session, it is the hope that through this arrangement the younger chemical engineers can get more out of a meeting and at the same time feel that they have had a definite contribution to it while the older engineers will have a chance to look back and also to see some of the modern concepts in fields in which they may have become unfamiliar.

Plant Trips

A variety of plants has been selected for the members and guests to visit. They are all in or near Houston.

Humble Oil & Refining Co. operates one of the largest installations of its type in the nation. The refinery has a crude oil charge capacity of 225,000 bbl./day, a thermal cracking capacity of 71,200 bbl./day, a reforming capacity of 17,000 bbl./day, and a fluid catalytic cracking capacity of 25,000 bbl./day. Humble is presently engaged in increasing its crude distillation capacity by 18,000 bbl./day. A new benzyl-methyl-ethyl ketone dewaxing plant was put on stream in 1948. In addition to the regular run of petroleum products, butadiene, toluene, xylene, and other solvents are produced.

Shell Oil Co.'s refinery at Deer Park has seen a great deal of construction activity. Recently a \$20,000,000 lubricating oil plant was built; this plant processes 2,800 bbl. of oil/day. Shell has also recently completed a large maintenance shop. In 1946, a \$25,000,000 catalytic cracker was built. The Deer Park refinery maintains a crude oil charge capacity of 110,000 bbl./day, a thermal cracking capacity of 29,000 bbl./day, a reforming capacity of 17,000 bbl./day, and a fluid catalytic cracking capacity of 25,000 bbl./day.

Shell Oil Co.'s exploration and research laboratory is located in Houston on Bellaire Boulevard. It was completed in 1947 at a cost of more than \$1,000,000. Floor space of 45,000 sq.ft. was provided in the laboratory. Emphasis here is on research and development in exploration and production tools and methods rather than refinery practice.

Sheffield has been in Houston since 1942. The company is engaged in the production of pig iron and steel from East Texas ore, Central Texas limestone, and Oklahoma and Arkansas coals. In addition to the usual steel products, fencing nails, barbed wire, etc., are produced. Recently officials of the company announced the construction of a pipe plant in Houston to be operated by Sheffield and the A. O. Smith Corp. This pipe plant reportedly will cost \$5,000,000.

Diamond Alkali is a newcomer to Houston. The company is carrying on operations in a recently completed \$14,500,000 plant on the Ship Channel. Plant covers an area of 325 acres. Products manufactured are caustic, chlorine, and perchloroethylene. Reports indicate that 220 tons of liquid chlorine and 240 tons of caustic in addition to perchloroethylene are produced.

Mathieson Chemical Corp. has a vital interest in Gulf Coast chemical development. The company recently acquired two H_2SO_4 and phosphate fertilizer producers, namely Southern Acid and Sulphur and Standard Wholesale Phosphate and Acid Works, Inc. Mathieson Chemical, the nation's fifth largest producer of alkalies, manufactures the following products in the Gulf Coast area: H_2SO_4 , ammonium phosphate, ammonium sulfate, phosphoric acid, phosphate, and sulfur.

Champion Paper & Fiber Co. operates mills at Hamilton, Ohio, Canton, N. C., and Houston, Tex. The Houston plant covers one-half the site of 162 acres on the Ship Channel. It ranks fifth in the industry. It is a leading maker of white paper. Champion Paper & Fiber in its three plants employs some 2,800 men. Sales approximately equal \$100,000,000 and capacity is 450,000 tons. The Houston plant has undergone a postwar expansion of \$7,000,000, plus a recent addition of a 1,000-ton paper machine.

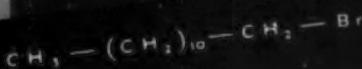
Consolidated Chemical Industries has been in operation since 1917 and it employs approximately 250 people. They manufacture H_2SO_4 , HCl, sodium sulfate, sulfate of alumina and alum.

Lone Star Cement Co. was founded in 1916 and is located on Manchester Road on a 16.18 acre site. Its production capacity is equivalent to 2,000,000

(Continued on page 26)

Look to DOW for

lauryl bromide



Lauryl Bromide, one of the bromides offered by Dow, is used in the manufacture of quaternary ammonium compounds and in other organic systems.

PROPERTIES:

| |
|--|
| An amber liquid. |
| Molecular weight 249.2 |
| Boiling range at 10 mm. Hg., 5-93% 136.6-193.5°C. |
| Specific gravity at 25/25°C. 1.021 |
| Freezing point below 40°C. |
| Refractive index at 25°C. 1.457 |
| Flesh point 144°C. |
| Fire point 168°C. |

SOLUBILITY:
(approximate),
grams per 100
grams solvent,
at 25°C.:

| | | |
|----------------------|-------|-----|
| Acetone | | 00 |
| Benzene | | 00 |
| Carbon Tetrachloride | | 00 |
| Ether | | 00 |
| n-Heptane | | 00 |
| Methanol | | 11 |
| Water | | 0.1 |

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MIDLAND, MICHIGAN

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of LAURYL BROMIDE

The Dow Chemical Company
Dept. D
Midland, Michigan

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Company _____
Address _____
City _____ State _____

DOW

CHEMICALS

INDISPENSABLE TO INDUSTRY
AND AGRICULTURE

AERIAL VIEW PFIZER SYNTHETIC PLANT AT GROTON



Shown above is a new plant for the manufacture of fine chemicals by organic synthesis at the Groton (Conn.) site of Chas. Pfizer & Co., Inc. Although Pfizer's plant in Brooklyn has been producing fine chemicals by both fermentation and synthesis methods, the new Groton plant will balance the company's capabilities to produce chemicals by the most expedient and economical methods. Products being produced initially at the new Groton unit include caffeine, theophylline, and other related compounds, used principally in the manufacture of pharmaceuticals. Production of synthetic caffeine will augment manufacturing facilities of Pfizer's Maywood (N. J.) plant where caffeine is prepared from natural sources.

I.I.T. OFFERS CHEM. ENG. FELLOWSHIP

Illinois Institute of Technology is now accepting applications for the 1950 Standard Oil Company (Indiana) fellowship in chemical engineering, according to Dr. W. A. Lewis, dean of the graduate school.

The award of \$1,700 will be made to the successful applicant. The only stipulation made in the grant is that the research deal with some phase of chemical engineering of general interest to the petroleum industry.

If the two leading candidates are eligible for benefits under the G.I. Bill of Rights, each will be awarded a fellowship.

Term of the fellowship will begin September 1950. Applications must be received by March 15, 1950. Further information and application blanks may be obtained from the Dean of the Graduate School, Illinois Institute of Technology, Chicago 16.

ENGINEERS HONORED BY ENG. INST. CANADA

By unanimous vote, the Council of The Engineering Institute of Canada recently elected four engineers to Honorary Membership in the Institute. They are J. B. Challies, vice-president and executive engineer, Shawinigan

Water & Power Co., Ltd., Montreal; Lillian M. Gilbreth, consulting management engineer, Montclair, N. J.; Sir Frank Whittle, inventor of the jet engine; and Clarence R. Young, former dean, Faculty Applied Science and Engineering, University of Toronto.

DU PONT CONTINUES GRANTS-IN-AID

The Du Pont Company has authorized, for the second year, \$100,000 for grants-in-aid to universities to "stockpile" knowledge through the advancement of fundamental science.

These grants-in-aid are for unrestricted use in the field of fundamental chemical research. This plan of assistance was inaugurated last year by Du Pont on a trial basis.

The grants are for the 1950-51 academic year. They provide \$10,000 for each of 10 universities, all of which received similar awards from the company for the present school year. The company also provide \$20,000 to the University of Chicago for a calendar year 1950 membership in its Institute for the Study of Metals.

The universities select the research projects for which the grants will be used, the only stipulation being that they be free from any commercial implications at the time the work is initiated.

The company emphasized that there

shall be complete freedom in the communication and publication of the results of the research work supported by the grants.

Institutions which will receive \$10,000 grants each are: California Institute of Technology, Cornell University, Harvard University, Massachusetts Institute of Technology, The Ohio State University, Princeton University, Yale University, University of Illinois, University of Minnesota, and University of Wisconsin.

REACTOR TRAINING SCHOOL BEGUN

Advanced training in the field of reactor development will be given government and industrial scientists and engineers at a newly established Atomic Energy Commission Reactor Development Training School at the Oak Ridge National Laboratory.

The emphasis on the new school will be to supply as quickly as possible scientists and engineers with formal training in reactor development. The students will fall into three categories: a. Engineers from industrial organizations who will remain on their companies' payrolls while attending the training school. b. Employees of other atomic energy laboratories or other government agencies detailed to Oak Ridge for training. c. Recent college graduates hired by Oak Ridge National Laboratory who will be trained as regular employees and will then be available for transfer to reactor groups throughout the atomic energy program.

Present plans call for about 60 students to be trained at one time, about 30 students in categories a and b and an additional 30 in category c. The school will operate continuously. All students will be required to have complete security investigation and clearance and the lectures and study material will be classified. Selection will be made by the Commission from qualified applicants on the basis of the need of the organization with whom its applicant is affiliated for personnel trained in reactor development, its potential contribution of the applicant to the AEC programs, and his academic record.

The shortage of trained men in the reactor development field has seriously hampered the national program for design and construction of new types of nuclear reactors.

Dr. F. C. Von der Lage, former director of the training division of the Oak Ridge National Laboratory has been named director of the Reactor Development Training School.

(Continued on page 22)

DURCO PRESENTS A NEW, IMPROVED PLUG VALVE

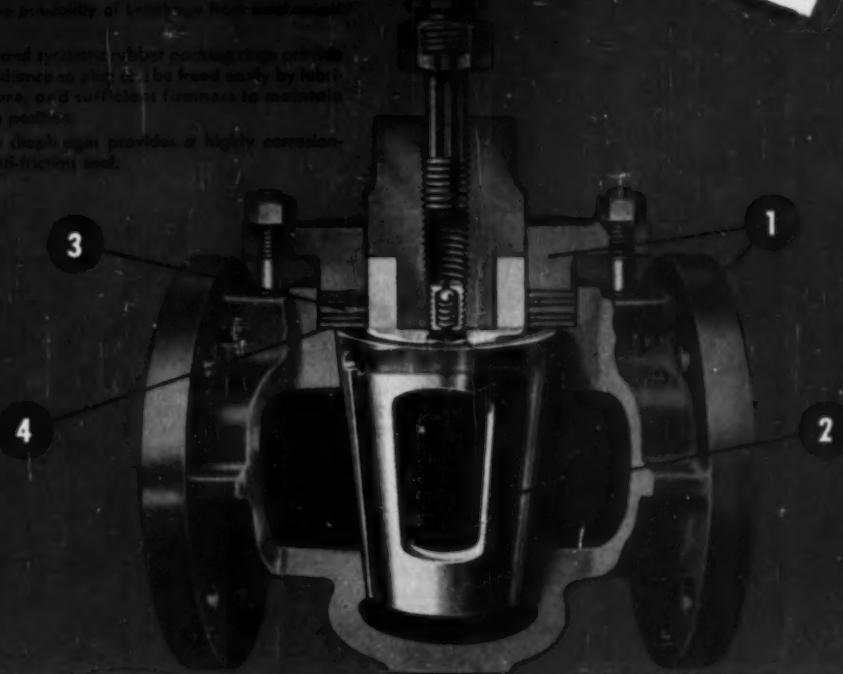
The new Durco Type A plug valve has been designed to overcome the disadvantages of previous types. The improved design features a composite plug which is more corrosion resistant than other compositions, and it utilizes both metal and ceramic materials.

This distinctive plug valve is the result of many years of experience in the manufacture of valves for corrosive services. The new design has been developed to meet the needs of the chemical industry, and the use of the best materials, assembly methods and processes of the Durco plant assure maximum reliability and long life of the valve.

1. Durable and corrosion-resistant packing rings provide sufficient resistance to plug to allow freed energy by friction pressure, and sufficient firmness to maintain proper plug position.

2. A Teflon diaphragm provides a highly corrosion-resistant, anti-friction seal.

FOR CORROSIVE
SERVICE



The DURCO Type A is a top-fabricated plug valve for general chemical service at pressures up to 1,200 lbs.

The mechanical design, as well as the composition of the alloys used in the construction of the valve, are the result of 50 years of intensive corrosion research. Special tooling and quantity manufacture make it possible to offer this valve at very attractive prices.

Available sizes: 1", 1½", 2" and 3". Delivery of valves with Durcor 20 bodies and composite plug from stock.

Write for a copy of Bulletin 626. Or, if you prefer, a Durco engineer will be glad to discuss your problems with you, at any time.



THE DURCO CO., INC.
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Bronx & Sons is principal distributor

INDUSTRIAL NEWS

(Continued from page 20)

HOOKER HAS ALKALI STEEL DESCALER

Hooker Electrochemical Company, of Niagara Falls, N. Y., is making available generally both a product and a process which may replace the classic method of cleaning steel and other metals in an acid bath. The Hooker patented descaling process is based on a fused alkali bath and up to the present has been used in a relatively small number of commercial installations. The new process resulting from developments starting in 1937 and introduced on a small scale in 1944, has approximately 40 units operating in 31 plants. Over 20 different individual applications of the process are in use at the present time but current experimental work indicates that even more applications are possible.

The process makes use of a fused alkali bath followed by a water quench and a short acid dip for most applications. For stainless alloys a second dip in nitric acid is used to brighten and passivate the surface. In the few industrial installations to date, over 16 different types of ferrous metals have been descaled. Among these are high alloy steels, tool steels, cast iron and wrought iron.

Although the process was originally developed for descaling stainless steel, it has since been found extremely versatile in its applications. In desanding castings for example, it completely removes the sand and exposes any pitting or pocketing due to faulty casings.

The Hooker descaling process is generally applicable to any metal or alloy which is not attacked by molten caustic soda at 930° F. One of the first fused salt descaling methods, known as the electrolytic caustic process, was introduced thirteen years ago by the Hooker Company. The method was in use for several years, but was never widely accepted on a large scale.

Attempts were made to apply this method to stainless steels which were just beginning to become commercially important, but their high electrical resistance made it unsuitable. Acid pickling took an excessively long time in most cases precluding the possibility of continuous treatment by this method. Some forms required as many as four successive annealing-pickling operations. Thus base metal losses were high averaging between 1 and 2 per cent for each cleaning. In addition material was often badly etched.

To overcome these shortcomings, Hooker developed a new process which

descals without pitting or loss of base metals. Mill scale, heat treating scale and rust are all converted to an acid soluble oxide. Acid consumption is relatively small and the salt bath may be used for years with only small additions to replace drag-out.

For the salt bath a mild steel tank is used and any of the three conventional methods of heating may be employed (external gas firing, immersion tubes of various types or immersion electrodes). Except for temperature controls, no auxiliary equipment is required. As a result many types of galvanizing or heat treating baths can be converted by simply removing the contents and charging with Virgo Salt. Other equipment required is relatively simple, consisting of a tank for water quench and an acid dip tank. For stainless steels a second acid tank for nitric acid dip is needed. For batch operations a traveling overhead monorail crane handles work from one tank to the next. The process is applicable to continuous work for strip wire and wire rod.

NEW GRANTS FOR M.I.T.

Industrial grants-in-aid totalling \$800,000 to the Massachusetts Institute of Technology have been announced by Dr. James R. Killian, Jr., president of the Institute. The grants bring total gifts to the Institute in its current development program to \$6,526,914.02.

Grants announced included \$250,000 from the United Fruit Company of Boston; \$50,000 from an unnamed Massachusetts corporation; \$250,000 from the Cities Service Research and Development Company of New York; and \$250,000 from the Standard Oil Company of California.

The United Fruit grant, "to support the Institute's program of research," is earmarked to be invested with endowment and other funds until the principal may be expended upon mutual agreement between the company and the Institute, the income from invested funds to be allocated each year to fields jointly selected by the two parties.

These fields include such projects as the Laboratory for Biology and Food Technology and the entire range of the Institute's activities that are unclassified from the point of view of government security. Income from the fund may be applied to fellowships, operating expense and other appropriate types of expenditures.

The Standard Oil Company of California specified that a "substantial part" of its grant be applied to chemical engineering and chemistry, nuclear science and engineering, and research projects in lubrication, friction, and wear and corrosion.

The Cities Service Research and Development Company grant sustaining M.I.T.'s current development program is to be applied to research and development work in the fields of nuclear physics and chemistry, mechanical engineering, and chemistry and chemical engineering. The grant is payable at the rate of \$50,000 a year.

ECUSTA PAPER BOUGHT BY OLIN INDUSTRIES

Olin Industries, Inc., which was licensed recently by Du Pont to make cellophane, purchased the Ecusta Paper Corporation at Pisgah Forest, North Carolina, and will launch its entrance into the cellophane industry through location of its initial facilities at that plant.

In announcing the purchase of the Ecusta Company, J. M. Olin, president, said the facilities acquired would shorten by four to six months the time required for Olin Industries to begin the manufacture of cellophane.

The Ecusta company manufactured cigarette paper and the manufacturing processes of these products are similar to the manufacturing processes used in making cellophane.

"The Ecusta Paper Corporation already has sufficient capacity for supplying treated water, steam and most of the power to the 8-machine cellophane installation which we propose to make at the outset," Mr. Olin said.

Ecusta will continue to produce its present line of high grade paper, since existing facilities will not be disturbed by the cellophane manufacturing installation. The purchase price involved in the transaction was not announced.

DPI DISSOLVED

Distillation Products, Inc., the wholly-owned subsidiary of Eastman Kodak Company, was dissolved as a separate corporation and became a division of the parent company on December 25.

The new Kodak division will be known as Distillation Products Industries and thus retains the initials DPI, widely used in its advertising.

The division will continue the same manufacturing and selling activities with no change in personnel.

DPI is a pioneer in molecular distillation processes and was owned and run jointly by Kodak and General Mills, Inc., from 1938 to July, 1948. At that time Kodak purchased General Mills' interest.

Main activities of DPI are the production of vitamins, the manufacture of high-vacuum equipment and the making of molecular stills, widely used in the chemical industry.

Which Centrifuge do I need?

There are differences in the application of centrifugal energy making one centrifuge the best answer to your particular separating or clarifying problem.

Each centrifuge below has a specific function which makes it preferred over others under certain conditions.

The Sharples Corporation alone manufactures *the complete line*. Therefore, after analyzing your problem, a Sharples engineer can make a truly unbiased recommendation. He is always at your call.

SUPER-CENTRIFUGE



A tubular bowl centrifuge which develops the highest centrifugal force commercially available. Can separate immiscible liquids with extremely small differences in specific gravity.

D-2-CENTRIFUGE



A disc-type centrifuge employing the stratification principle of high separating efficiency combined with high through-put capacity.

MOZJECTOR



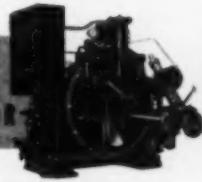
A high efficiency disc-type centrifuge that continuously discharges solids as well as performing the clarifying or separating function.

AUTOJECTOR



This disc-type clarifying or separating centrifuge intermittently and automatically discharges solids when a pre-determined "cake" has been built up.

SUPER-D-HYDRATOR



Used for the recovery of crystalline solids from liquids, this high capacity centrifuge can efficiently handle slurries with 15 to 60% solids.

SUPER-D-CENTER



A high capacity centrifuge used for the recovery of solids from liquids, the clarification of liquids or the classification of solids. Capable of handling a wide variety of solids.

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Sharples



ANNUAL MEETING

(Continued from page 12)

of the A.I.Ch.E. which was made to determine what percentage held professional engineering licenses. The poll showed, that of those replying (20% of the membership) 58% of the active members and 29% of the junior members were licensed. An active discussion from the floor on the pros and cons of engineering registration followed the formal remarks of the panel members.

A panel discussion on "Training of Young Engineers Within Industry" was organized and led by P. V. D. Manning, International Minerals and Chemicals Co., and Chairman of the Institute's Committee on Professional Guidance. Speakers on the panel were K. B. McEachron, Jr., General Electric Co., A. J. Lange, Joseph E. Seagram & Sons, Inc., Jessie McKeon, Westinghouse Electric Corp., and Webster N. Jones, Carnegie Institute of Technology. The discussion was divided into two parts: Part I was concerned solely with what industry could do alone adequately to train graduate engineers to fill the positions arising in their organization and Part II took into consideration university and industry working along cooperative lines and their joint responsibility to provide the right kind of engineering training.

Many of the general papers on the Pittsburgh technical program pertained to heat transfer and distillation studies. Two papers on the heat transfer characteristics of liquid sodium-potassium alloys were presented. This alloy is of interest as a possible cooling medium for nuclear reactors. Richard N. Lyon, Oak Ridge National Laboratory, reported on methods of predicting heat transfer coefficients of alloys of these metals and compared the empirical predictions with experimental data. "Heat Transfer with Sodium-Potassium Liquid Alloys" was the title of the other paper by R. C. Werner, E. C. Ring and R. A. Tidball, of Mine Safety Appliances Co. Fluid solids systems received attention in two papers one by J. R. Bowman, Mellon Institute, the other by Max Leva, U. S. Bureau of Mines. J. R. Bowman reported the development of a mathematical analysis of the fluidized state on a semi-quantitative basis. He said that the analysis was mainly important as a guide in understanding the mechanism of fluidized systems and was in no sense quantitative enough to be used for design purposes.

T. K. Sherwood and W. H. Linton, M.I.T., presented results of an investigation entitled, "Mass Transfer from Solid Shapes to Water in Streamline and Turbulent Flow." The authors dis-

cussed the effect of the Schmidt group on mass transfer in turbulent flow obtaining data on the rate of solution of cast tubes, cylinders, plates and spheres of benzoic acid, cinnamic acid and betanaphthol. Test objects were placed in water and data obtained in both turbulent and streamline flow.

An interesting motion picture study of heat transfer and flow characteristics of liquids flowing in annuli containing plain and transverse finned tubes was presented in conjunction with a paper on this subject by J. G. Knudsen and D. L. Katz of the University of Michigan. Experimental work was performed on a number of tubes, all of the same inside and outside diameters but with different ratios of fin height to fin spacing. Flow patterns were shown photographically by the injection of a dye into the stream and eddy patterns were clearly discernible in the space between fins and adjacent to the tube surface. A range of Reynolds numbers from 1000 to 70,000 were investigated.

RAPID SELECTOR TO SPEED LIBRARY SEARCH

A recently developed type of "mechanical brain" for sifting through scientific knowledge to select those facts needed for specific research jobs is being perfected jointly by the U. S. Department of Agriculture and the Atomic Energy Commission.

The machine, called the rapid selector, was designed to help the scientist to keep abreast of new ideas and developments in his own and related fields.

The selector operates like a research worker looking through the cards in a library catalogue, but at much greater speed. With properly coded entries, the machine will scan up to 120,000 subject entries per minute. Moreover, it will reproduce, on the spot, an abstract of a document or, if properly set up, the original document.

The present working model of the rapid selector stems from a suggestion of Dr. Vannevar Bush, wartime head of the Office of Scientific Research and Development. The development was carried out by Engineering Research Associates, Inc., under contract with the Office of Technical Services, Department of Commerce. Continuing development to provide greater flexibility in use is being carried on by the Department of Agriculture with the support of the Atomic Energy Commission.

A 2000-foot reel of film used in the present selector provides space for text and code for 60,000 abstracts or an equal number of text pages. As many

as six different coded entries may be made for each abstract or page, or a total of 420,000 entries on the entire reel. If more entries are needed for complete coding of a single item the text is repeated, giving space for an additional six codes. Since the machine scans 500 feet of film per minute, the entire reel of film can be scanned in four minutes.

Scanning is done by means of banks of photoelectric cells which read the code. When the desired information comes along the cells trigger a camera equipped with a stroboscopic light source lasting two-millionths of a second. The short duration of the light source will effectively stop the moving film, producing a sharp image which may be enlarged for convenient reading.

First use of the selector by the Atomic Energy Commission will be for the maintenance of records of new research with radioisotopes. Isotope information will be catalogued by physical characteristics such as the energy and type of radiation, by applications such as use in medical treatment and diagnosis, by method of production, and other factors.

Saving in cost will be effected by supplying atomic energy libraries with reels of film instead of with the equivalent number of printed documents.

ENGINEERS DEFEAT MANDATORY REGISTRATION

In a test vote of Massachusetts engineers to determine whether the State should keep its present permissive registration law or adopt a mandatory law compelling all engineers to become licensed, a clear majority was returned in favor of the permissive law. The referendum was sponsored by the Engineering Societies of New England and the Massachusetts Society of Professional Engineers. Ballots were mailed to 10,200 of the State's engineers, all members of the two previous societies plus those of the Worcester Engineering Societies, the Engineering Society of Western Massachusetts and the Pittsfield Section of the A.I.Ch.E.

Of the ballots sent, about 42 per cent were returned, and 1829 were in favor of the mandatory law, and 2355 were opposed to the legislation. The present permissive law has been in effect since 1941. Last year a bill was introduced changing the law to the mandatory form, but was withdrawn because of opposition and the understanding that a state referendum would be held.

Members of the A.I.Ch.E. in the State voted three to one against the mandatory form.



10 Months' Service with AlCl_3 , HCl , and FeCl_3

...WITHOUT CORROSION

This sparger unit—made of HASTELLOY alloy C—is used to introduce gases into a catalytic reactor used in the production of styrene for polystyrene plastics and for synthetic rubber.

Machine marks are still visible on the sand-cast surface of this unit, although it has already been in service for over 10 months in contact with aluminum chloride, hydrogen chloride, ferric chloride, and hydrocarbon gases and liquids at temperatures of 240 to 270 deg. F. And it is expected to last indefinitely under these severely corrosive conditions. The unit previously used required replacement every three or four months at considerable expense and loss of time.

HASTELLOY alloy C is available in a variety of wrought forms and also as conventional or precision castings to meet your requirements. In addition to its excellent corrosion resistance, this alloy has high strength—even at red-heat temperatures—and it can be readily fabricated by most common methods. For more complete information, write for a copy of the booklet, "HASTELLOY High-Strength, Nickel-Base, Corrosion-Resistant Alloys," Form 3361.

The trade-marks "Haynes" and "Hastelloy" distinguish products of Union Carbide and Carbon Corporation.

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Los Angeles — New York — San Francisco — Tulsa

TEXAS

(Continued from page 18)

bbl. of cement yearly and it employs 235 people.

Goodyear Synthetic Rubber recently began the production of cold rubber at the plant it operates in Houston. This plant is government owned. The plant had previously produced 600,000,000 lb. of GRS. The products of this plant are marketed under the name of Chemigum. Construction on the Goodyear Synthetic Rubber plant was begun in 1942 and the cost was approximately \$13,300,000. Rated capacity is 60,000 long tons/year.

Mexico Is Near

A post-convention trip to Mexico is an added attraction at the Houston Regional Meeting of the Institute. The trip will be made regardless of the number of members and guests who signify their intention of going. Two trips have been arranged; one trip will be for five days, the other for ten days.

The group taking tour No. 1 will leave the Houston Municipal Airport at 3:30 P.M., Wednesday, March 1, by Pan American Clipper to Mexico City nonstop, arriving at 7:49 P.M. At Mexico City they will be transferred to the fabulous Del Prado Hotel for accommodations and dinner. On Thursday there will be an all-day excursion to the Shrine of Guadalupe and the Pyramids of the Sun and Moon. Friday the group will motor to the delightful tower of Cuernavaca, famous since the days of Cortez, after lunch continue the drive to Taxco, picturesque mountain village, which has retained its 18th century charm and return to Mexico City that night. Saturday morning will be devoted to a city tour, visiting the famous cathedral, Palace of Fine Arts, residential districts, etc. The afternoon will be free for shopping or relaxation. Sunday the group will leave at 10:30 A.M. by Pan American Clipper arriving back in Houston at 2:03 P.M. where connections will be available to their home towns.

Itinerary No. 2 is for ten days. A start from Houston will be made at 3:30 P.M. on Wednesday, March 1, by Pan American Clipper, arriving at Mexico City in time for dinner at the Del Prado Hotel. On Thursday there will be an all-day excursion to the Shrine of Guadalupe and the Pyramids of the Sun and Moon. On Friday there will be an overnight trip to Cuernavaca and Taxco. Saturday the group will visit the tin and silver shops of Santa Prisca, and the many charming nooks of Taxco, returning to Mexico City after lunch.

Sunday there will be a drive to the gay Floating Gardens of Xochimilco

and the gondola ride along its flower-lined canals. En route stops will be made at Chapultepec Park for the band concert and charro parade. The afternoon is free for those who want to attend the bull fights. Monday, a tour of the city will be made. Tuesday, an off-the-beaten-track trip to the arts and crafts Valley of Toluca, will be made. Here may be seen the Indians making baskets, pottery, etc.

Wednesday and Thursday will be used for a trip to Acapulco on the Pacific Coast, where accommodations will be made at the Hotel de las Americas, returning to Mexico City Thursday evening. Friday, the party will leave at 10:30 A.M. for Houston.

Prices for tour No. 1 are: single accommodations, \$184.36, double accommodations, \$173.86. Prices for tour No. 2 are: single accommodations, \$261.86 and double accommodations, \$254.36.

Included in the rates are: all transfers between cities and airports, air transportation via Pan American World Airways, accommodations at the Del Prado Hotel while in Mexico City, all meals which may be taken at any restaurant or hotel in Mexico City à la carte with complete choice of menu, U. S. transportation taxes, and air transportation to Acapulco.

Persons interested in one of these tours should contact Pan American World Airways, 801 Walker Ave., Houston, Tex., or call CE-9331 while at the convention.

Havana by Air

Members of the Institute who are interested in visiting Havana may use the opportunity presented to them in Houston. They can fly by Braniff International Airways on either a full-week or five-day trip. Both tours will leave Houston at 10:40 A.M., Wednesday, March 1, arriving at Havana at 4:35 P.M. Those who wish may leave Havana at 9:35 A.M. the following Sunday reaching Houston at 1:00 P.M. in time to reach home and the office on Monday morning.

Prices vary for each tour depending upon the hotel selected in Havana. For the shorter trip prices in double rooms vary from \$160.80 to \$134.80 and in single rooms from \$182.80 to \$138.80. Prices for the full-week tour in double rooms vary from \$198.30 to \$152.80 and in single rooms from \$236.80 to \$159.80. Included in these prices are the round-trip fare in a DC-4, ground transportation from and to the airport in Havana and accommodations. European plan.

Anyone interested should write Earl Sealey, Braniff International Airways, 513 City National Bank Building, Houston 2, Tex.

MATERIALS OF CONSTRUCTION COURSE

Newark College of Engineering has instituted a coordinated course on "Materials of Engineering Construction," on the graduate level. The course will cover all types of building materials from the viewpoint of service, production, corrosion, preservation, life, etc.

The course is being given by Dr. Charles L. Mantell with the help of outside lecturers, and specialists, and is open to others beside those taking a Master's degree.

Information on the course can be obtained from the College at 367 High Street, Newark 2, N. J.

CONFERENCE BY A.C.S., SPECTROSCOPY SOCIETY

The Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy, which is being jointly sponsored by the Analytical division of the Pittsburgh section of the A.C.S. and the Spectroscopy Society of Pittsburgh, will be held at the William Penn Hotel, Pittsburgh, Pa., Feb. 15, 16 and 17, 1950. An exposition of modern analytical equipment will be featured. Many papers are scheduled for the meeting including such titles as, "Progress in Spectrographic Instruments," "The Industrial Analytical Chemist in a Changing Scene," "The Determination of Fluoride," and "The Spectrochemical Determination of Magnesium in Cast Iron."

FURMAN AND VOLWILER A.C.S. PRES. 1951, 1950

Dr. N. Howell Furman, Russell Wellman Moore professor of chemistry, Princeton (N.J.) University, who developed new analytical techniques for the atomic bomb project, has been chosen president-elect of the A.C.S. He will head the society in 1951. For 1950 Dr. Ernest H. Volwiler, executive vice-president of Abbott Laboratories, North Chicago, Ill., is president. Dr. Volwiler succeeds Dr. Linus Pauling of the California Institute of Technology.

WE STILL NEED JAN., 1949 ISSUES

If readers have copies of the January issue of last year which have already served their purpose, we will be glad to pay 50 cents for each one. Send them to—*Chemical Engineering Progress*, 120 East 41st Street, New York 17, N. Y., postage paid. Indicate your name and address plainly on the outside or inside of the package.

LETTER TO THE EDITOR

WIRE RECORDINGS?

Sir:

The program for the Pittsburgh meeting of the A.I.Ch.E. which will be held in December was received by me in plenty of time to study the abstracts and decide I wanted to attend. But my work program just won't let me go that week.

Sure, I can read the papers when they are published—several months from now, that is, if I don't miss seeing that issue of "C.E.P." But I am interested in them now.

Even if I made the meeting, I would miss some papers because two I want to hear are being given at the same time.

There is an answer to this problem—obvious to me. Why not make wire recordings of each session?

These could be reproduced in quantity and made available to individuals or companies who were not able to hear the paper when it was first given. The cost once it is started should be very reasonable. In fact this project could easily be made self-supporting by a slight subscription fee to the users, who would furnish their own player to use in their own office or home.

Finally, the way to distribute them. Why not let this be handled by the local sections? This would cut out any administrative load and would speed up the passing on of a recording from one user to the other.

This seems to be so simple a solution to a problem that is important to me. Why not do it!

Elmer P. Foster,
Nov. 21, 1949 Scotch Plains, N. J.

TENN. VALLEY PROJECTS COVERED IN BULLETINS

Chemical Engineering Report No. 5, "Development of Processes for Production of Concentrated Superphosphate," is another in the series of technical monographs the Tennessee Valley Authority is compiling to cover its major projects. Reports 1 and 2, entitled, "General Outline of Chemical Engineering Activities," and "Development of Processes and Equipment for Production of Phosphoric Acid," respectively, were published recently.

These bulletins are for sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., at the price of 45 cents. A limited number is available for free distribution obtainable by writing to: Tennessee Valley Authority, Division of Chemical Engineering, Wilson Dam, Ala.

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MARGINAL NOTES

News of Books of Interest to Chemical Engineers

Titanium—Yesterday, Today

Titanium—Its Occurrence, Chemistry, and Technology. Dr. Jelks Barksdale. The Ronald Press Co., New York (1949). 301 pp. \$10.00.

Reviewed by Rollin P. Smith, Chief Development Engineer, National Lead Co. (Titanium Div.), South Amboy, N. J.

DR. BARKSDALE has practically filled the great gap that has existed in the literature of titanium since Thornton's A.C.S. monograph No. 33 was published in titanium's dark ages. "Titanium" will be the bible and bibliography of workers in this field and the reference of those more casually interested until, as the subject grows, it is again brought up to date.

In a cohesive, well-organized manner a vast welter of references is presented in readable form. Actually the book consists of a literature and patent survey, exhaustive and complete, arranged according to an outline which permits painless access to information for those interested in only certain phases of the subject.

With titanium currently the "hottest" element in the periodic table, its literature scarcely can be kept up to date. Vast research and development programs are continually bearing new fruit in titanium metal, titanium oxide, single crystals, titanium organic compounds, titanate-bearing porcelain enamels, and titanium flame-proofing compounds. This situation tends to make Barksdale's book most timely and his determination to present it praiseworthy.

"Titanium" is, as the reader might expect, presented as seen through the research chemist's eye. Dr. Barksdale has been fair and impersonal throughout. Engineers and production men may take some exceptions to his point of view. Actually the book contains but a modicum of engineering significance. Commercially practiced methods are not distinguished markedly from other apparently technologically sound methods.

In his attempt to reconstruct the probable history of titanium and the development of titanium pigment industries, the author appears to have done an adequate job.

All technical men will do well to read this book to understand current interest

and progress in this field. Indeed, Dr. Barksdale has made this an interesting experience as he leads the reader smoothly through history, geology, technology, commercial applications and testing procedures of titanium, its minerals and compounds. It will be a welcome background for new work.

Research and the Library

Sources of Engineering Information. Blanche H. Dalton. University of California Press, Berkeley and Los Angeles, Calif. (1948). 109 pp. Second Printing (1949). \$4.00.

Reviewed by J. H. Perry, Technical Investigator, Du Pont Company, Wilmington, Del.

THIS compilation is stated to be "the revised edition of a syllabus originally written to be used with lectures on the use of the library, presented for engineering faculty members and graduate students of the University of California who wished to learn how to make effective use of library facilities when engaged in research." The present revision is hoped to "be of help to those engineers, always pressed for time, who must find short cuts to printed research materials and to those librarians whose technical collections present difficult reference problems."

This book is composed of seven major sections: (1) Indexes to Periodicals and Serial Literature, (2) Abstracts, (3) Location of Articles; Identification of Periodicals, (4) Bibliography, (5) Reference Books, (6) The Trade Catalog Collection, and (7) Standards and Specifications. Some of these sections are divided into more detailed categories which in turn are usually further subdivided.

There is no index and since references to an individual subject are scattered throughout the seven subdivisions, it is necessary to make a page-by-page search for a specific subject. Thus, "Aeronautics" is found in at least eleven places and "Mining" in at least eight places. Some duplications of entries in different sections carry different dates. There are five separate lists where one must look for such bibliographical guides as bibliographies, abstracts, indexes, and the like. The section on "Abstracts" is in three parts.

Contents of each subdivision of this book are incomplete as to the more worth-while items and include too many mediocre or less valuable items. Among the reference books, for example, there is no entry under "Chemical Engineering." Many errors appear due to the faulty checking and proofreading and there are also some inconsistencies which were noticed by this reviewer. The entry under "Heat Conduction" actually deals only with convective heat flow and is one of the least useful "Reference Books" that are available on either subject. Some of the entries, such as the Experiment Station Record which ceased publication with the December, 1946, issue, are no longer available. The 1939 A.I.Ch.E. Chemical Engineering Library Book List is mentioned but the later list, for 1947, is not cited. The Engineering Index is listed under "Abstracts" but is not mentioned under "Indexes" except in a sentence under Industrial Arts Index. There is no mention apparently of either Human Engineering or Engineering Management.

This reviewer can see a real need and an appreciable market for a booklet on this subject—if a critical and representative list of the principal publications of the scientific and engineering fields is prepared and assembled in an alphabetical or other logical order. Addition of an index and also counsel on the use of a technical library would be worth while to the proposed booklet. Such a booklet could be recommended especially to student engineers even at \$4.00 and would also be valuable to more experienced engineers.

For Power Plant Engineers

De Laval Engineering Handbook. Austin H. Church and Hans Gartmann. De Laval Steam Turbine Company, Trenton 2, N. J. 266 pp. \$2.00.

Reviewed by W. T. Nichols, Director, General Engineering Department, Monsanto Chemical Co., St. Louis, Mo.

THIS is an excellent engineering handbook, especially adapted to the needs of power plant and field engineers, but useful also to designers and engineers of all sorts engaged in industrial work. Data are listed in sections labeled General, Steam Turbines, Centrifugal Pumps, IMO Pumps, Centrifugal Compressors, Helical Reduction Gears and

Worm Reduction Gears. The General Section takes up about a third of the book and is packed with data useful in all sorts of engineering work. Contents of the other sections are described by the section names and, in general, these subjects are competently covered by the data included. Typography and illustrations are excellent. Even in the kind of tables where crowding of figures is unavoidable, the figures are easily legible.

It is perhaps a matter of opinion that the book would be improved if certain data were presented in a different manner. Sections on "Functions of Numbers" and "Resistance of Valves and Fittings to Flow of Fluids" are examples. Other methods of presenting such data have gained wide acceptance and are believed to be more usable. The same remarks apply generally to the section on "Fluid Data."

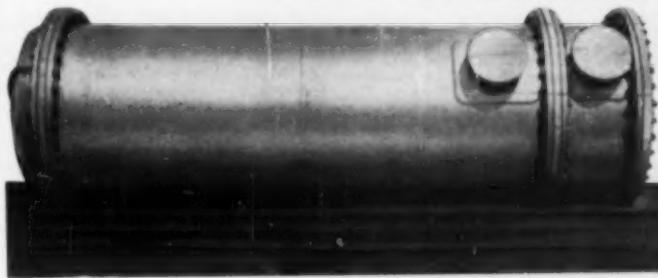
The book covers, for its size, a useful and surprisingly large area of engineering information. However, there are some curious omissions. For example, there is a good section on flat leather belting but V-belts are not even mentioned.

No doubt frequent consultation and long usage would make it possible for an engineer to locate data readily in this book, but for one seeing it for the first time, the arrangement is unusual and disconcerting. The book is sectionalized into seven divisions, each designated with the letter of the alphabet which is the first initial letter of the section name. Page numbers in each section are preceded by the letter designation for that section. Since the section designations are not in alphabetical order (G, T, P, I, C, R, W), the letter designation does not indicate in what portion of the book the section occurs. Furthermore, there is no comprehensive index, but rather a table of contents preceding each section. It is necessary to guess in what section the desired data may have been placed. This is not too difficult in most cases, but the possible effect may be realized from the fact that data on *pipe friction pertaining to gases* occur on page C-18 in the Centrifugal Compressor Section while the *friction data for liquids* are on pp. G-85-98 in the General Section. The indexes, themselves, could be improved. Although confined to gases, data on page C-18 are listed simply as "Pipe Friction." On the other hand, data on pp. G-85-98 are indexed as "Pressure Losses from Pipe Friction," under "Fluid Data," and the engineer might well expect to find the gas data there. So important an item as determination of power required for pumping liquids is not indexed at all.

In spite of these observations, this handbook is recommended for the practicing engineer whose work requires the

(Continued on page 31)

Heliarc welded... WITHOUT FINAL WARPAGE OF THE SHELL



Aluminum Shell and Tube Heat Exchanger, one of two on the order 40" diameter 10' tube length. This unit is made of all aluminum, type 25 except the bolts, which are steel. Heliarc welded. The unit has a number of shell baffles, resulting in 6 shell passes. The welding in of these shell baffles created serious warpage problems for the Heliarc welding. However, DOWNTONTOWN was able to complete these exchangers without encountering any final warpage of the shell.

We of DOWNTONTOWN solicit your inquiry for heavy duty shell and tube equipment:

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Design and construction meet standard of A.S.M.E. or other agency specified by customer. All equipment of our design is sold on a guaranteed performance basis. We also fabricate to customer's drawings. Modern facilities available for checking welding operations by X-RAY. Write on your letterhead for DOWNTONTOWN literature on shell and tube heat exchangers.



SECRETARY'S PAGE

S. L. TYLER

The Report of Council meeting (last month, Dec. 4) usually appearing on this page, will appear on this page in the February issue of C.E.P.

Report of Council

This report of the activities of the Council of the Institute covers the period Nov. 1, 1948, to Nov. 1, 1949. During this period Council held nine meetings and the Executive Committee met twelve times. The Council meetings were held on the following dates: Nov. 7, Dec. 10, Jan. 7, Feb. 11, April 8, June 10, July 8, Sept. 7 and Oct. 7; and the Executive Committee meetings were held on the following dates: Nov. 7, Dec. 9, Jan. 6, Feb. 11, March 24, April 7, May 4, June 9, July 6, Aug. 5, Sept. 16 and Oct. 7. All these meetings were reported on the Secretary's Page of *Chemical Engineering Progress*; hence, this is more or less a summation of these monthly reports.

Membership

The membership of the Institute has continued to grow at approximately the same rate as for the last three years. The following table gives you the membership as of Nov. 1, 1948, compared with Nov. 1, 1949.

| Membership | Active | Associate | Junior | Total |
|---------------------|--------|-----------|--------|-------|
| Nov. 1, 1948 | 3313 | 398 | 5179 | 8890 |
| Elections | 404 | 61 | 689 | 1154 |
| Deceased | 24 | 2 | 7 | 33 |
| Resigned | 10 | 8 | 69 | 87 |
| Dropped | 12 | 2 | 191 | 205 |
| Elections rescinded | 1 | - | 7 | 8 |
| Nov. 1, 1949 | 3670 | 447 | 5594 | 9711 |

The net increase in membership during the period of this report is 821 compared with 1,147 for the year ending Nov. 1, 1948, and 1,080 for the period ending Nov. 1, 1947.

| | 1948 | | 1949 | | 1949-48 % of Increase |
|-----------|------|-------|------|-------|-----------------------------|
| | No. | % | No. | % | |
| Active | 3313 | 37.3 | 3670 | 37.8 | 10.8 |
| Associate | 398 | 4.5 | 447 | 4.6 | 12.3 |
| Junior | 5179 | 58.2 | 5594 | 57.6 | 8 |
| Total | 8890 | 100.0 | 9711 | 100.0 | 9.2 |

Publications

Chemical Engineering Progress, the official publication of the Institute, has continued to enjoy increased circulation through Institute membership and through subscriptions. There has been a 58% cir-

culation growth during the last two years. There were 13,339 copies of the October, 1949, issue mailed to members and subscribers in contrast with mailing of the first issue, namely, the January, 1947, issue, of about 6,300.

NEW A.I.C.H.E. MEMBERS ELECTED JANUARY 3, 1950

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L. G. Crunkleton
James A. Davies
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W. D. Harris
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Harry A. Lutz
Aaron E. Markham
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William L. Larcamp
John M. Lenoir
James S. Lester
John V. Lopez-Ona
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Richard D. Studwell
Max A. Turner
Richard H. Walker
Robert Ford Westall
David C. Woody
Bernard S. Wright
Earle F. Young, Jr.

DATA SERVICE

BULLETINS

1 • AIR HUMIDIFIER. For adding moisture to air, Armstrong Machine Works details in a bulletin, the place and function of the steam humidifier. Bulletin gives data on moisture content of materials, water in cubic feet of air at various saturations, desirable relative humidity in various industries, etc. Explains construction and operation of the steam humidifier both electrically and air operated, shows views of plants, data on how to select humidifiers, prices, capacities, installation, etc.

2 • CONTROL VALVE CATALOG. A new catalog of Rato-matic instruments for remote indicating, controlling and totalizing comes from the Fischer & Porter Co. Complete descriptions of instruments and controls, including construction and use detail. Principle of operation, flow sheets of installations, make for a catalog, complete and descriptive, of the instruments made by this company.

3 • SAFETY CATALOG. Wilson Products Inc., has a new 64-page catalog of industrial safety equipment. It contains data on eye and respiratory equipment, plus other technical and reference material. Discussions of respiratory hazards and proper respirators to use, care and maintenance, gas mask selector tables, etc.

4 • ROTARY FILTRATION PRINCIPLES. An explanation of the Filtration Engineers string discharge continuous vacuum filter. Drawings show the construction and operation, pictures of installations, details of washing mechanism and valves, etc. Diagrams of installations, text on pilot plant filters, typical applications in the chemical, paper, ceramics, etc., industries.

5 • VACUUM PUMP MANUAL. For industrial applications of vacuum pumps, F. J. Stokes Co. has issued

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a book on the production of high vacuum. Methods of selection plus examples, begin the dissertation, and throughout the book there are design views showing construction details, pictures of models available, plus performance to be expected, methods of cleaning the oil used in the pump, and then several pages of vacuum pump data such as typical problems and their solutions, charts on volumetric efficiency, performance analysis, vacuum constants, formulas, etc.

6 • MILLS, REFINERS, WASHERS AND CRACKERS. A catalog of the Farrel-Birmingham Co., Inc., showing its line of mills, rolls, Banbury mixers, plastic mills, pelletizers, etc. Shows with illustrations and with explanations,

the differences in various types of plastic and rubber machinery, gives general specifications, and details, equipment, and features of the products of this company made for the plastic, linoleum, powder, sugar, etc., industries.

7 • CENTRIFUGE DATA. From The Sharples Co., a bulletin on its line of continuous centrifuges which range upward from 13,200 times gravity. Principles of centrifugal separation is explained along with data on the supercentrifuge, with cutaway views and mechanical details. Industrial applications are given and specifications for the various special types of centrifuges made by the company are shown.

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8 • VALVE SIZE DATA. The Hammel-Dahl Co. has an engineering data bulletin which shows how to size a diaphragm valve for liquid, steam, gas. Charts are based on the use of a plug design with linear characteristics when per cent of maximum plug lift is plotted against per cent of maximum flow. Formulae are given, plus flow coefficients; examples of flow calculations through the valve are also shown along with a method of valve sizing by a heat balance method.

9 • GRAPHITE COMBUSTION CHAMBERS. For manufacturers of hydrogen chloride produced by burning hydrogen and chlorine, National Carbon Co. has issued a booklet describing graphite combustion chambers, and impervious graphite nozzles, along with a description of the process and equipment. Drawings of the assemblies, data on chamber capacity, etc., are all included.

10 • ELECTRIC HEATING UNITS. A complete catalog of electric heaters is new from the Edwin L. Wiegand Co. Four basic Chromalox units are described, strip, ring, tubular and cartridge, plus data on wattage, voltage, and sheathing material. In addition to immersion heaters, the catalog covers various industrial blower units, convection-type thermostats, hot plates, plus some engineering data on heat losses, etc.

11 • LABORATORY FURNITURE. For those interested in furnishing laboratories, Metalab Equipment Corp. has processed a new, extensive catalog which covers laboratory equipment. Includes service fixtures, fume hoods, cabinets, desks, plus comprehensive specifications on laboratory equipment and furniture.

12 • GLYCERINE MANUAL. For industry, the Glycerine Producers Association has made up a complete manual on glycerine, covering the chemical and physical properties, such as specific gravity, densities, freezing points, relative humidity over aqueous glycerine solutions, and references. Uses of the product, plus information on other books available.

14 • PUMP OPERATING MANUAL. An instruction book on the installation and operation of centrifugal pumps in corrosive service, has been issued by The Duriron Co. Manual covers installation, showing correct and incorrect methods of pipe connections, a section on operation of pumps which covers such things as starting pumps for the first time, assembly and disassembly of pumps, pumping pointers, and data on conversion factors, etc.

15 • PRESSURE GAGE SNUBBER. For protection of pressure gages from damage due to turbulent flow and surges, Parker Appliance Co. has a

one-page bulletin on a new pressure snubber. Snubbing chamber is on the side out of the direct line of flow and prevents surges in pressure from causing rapid needle fluctuations.

16 - 21 • FILTER LEAFLETS. Oliver United Filters has a series of six 4-page leaflets describing various types of filters. In general, each bulletin gives a schematic diagram on the construction, the operation and advantages of the particular type of filter described in the bulletin, data on available sizes plus pictures of installations. Sized for data files, the bulletins cover (16) the American continuous filter, (17) the vacuum saveall, (18) lime mud filter, (19) Kelly pressure filter, (20) precoat filter and (21) horizontal rotary filter.

22 • JACKET WATER COOLERS For cooling engine, compressor, and other cooling water the Young Radiator Co. has developed a series of jacket water coolers. Basically the units are water-cooling coils over which air is blown rapidly by huge fans behind the coils. Capacity tables giving the heat dissipation, water flow, and temperature performance are included. Units are also adaptable to cooling oils, hydrocarbon gases, and air.

23 • FACESHIELD. For those concerned with protection of themselves or other workers, from flying material, the Mine Safety Appliances Co. has a bulletin on faceshields. Of new design, the new headgear fits the natural contours of the head. Shields are in 4-in., 6-in. and 8-in. sizes and metal screen visors are available for protection from high temperatures.

24 • CLAD STEELS. A special publication of the Lukens Steel Co. for pulp and paper mills on corrosion resistance of clad steel. Illustrations for typical applications and flow sheets of the sulfite, sulfate and soda pulp operations have indicated applications of clad steels. Same treatment for paper-making operations. Data include lengths, widths, and gage thickness of available clad plates.

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25 • STAINLESS STEEL METER. A new stainless steel meter for the volumetric measurement of corrosive liquids is in production by the Buffalo Meter Co. Capacities range from 3 to 160 gal./min., available in 1 in. and 2 in. Specially designed for such corrosive products as caustic soda, acids, etc. Made in 316 Stainless Steel; measuring piston is hard carbon or other material.

26 • VISCOTROL. For engineering operations where viscosity variations occur during production, and where continuous and automatic control of viscosity is desirable, the Brookfield Engineering Laboratories have a new control. The instrument continuously measures and signals viscosity variations and can automatically activate control mechanisms. It can be supplied to control any viscosity from 2000 to 50,000 cp., and will respond to a viscosity change of 1 per cent. Bulletin available which shows instrument, typical installations, construction of instrument and operating details.

27 • SWIVEL JOINT. A new rotary swivel pipe joint containing a small amount of side flexibility to reduce breakage, is on the market by Marco Manufacturing Co. Special design eliminates wedge action of the ball against the gasket. Company tests indicate successful performance at continuous rotation up to 30 rev./min. Handles all fluids including corrosive fluids and acids and alkalis. Available $\frac{1}{2}$ in. to 1 in. pipe sizes.

28 • AUTOMATIC DRUM FILLER. For use where drums must be filled with liquids to a correct weight, Yale & Towne have a new air-operated drum filler which automatically cuts off when the desired weight is reached. Works on air pressure between 80 and 150 lb./sq. in. Flow material can be regulated and extreme accuracy is possible. One advantage is no electrical equipment

when solvent or hazardous chemicals are barreled.

29 • SKID-PROOF FLOOR. For insuring safer walking for workmen in slippery areas in chemical plants, a new abrasive rolled steel floor plate is in production by the Alan Wood Steel Co. The rolled plate includes an abrasive grain, and it can be sheared, drilled, countersunk, etc. Bulletin available. Plates can be had from $\frac{1}{8}$ in. to $\frac{3}{8}$ in. thick, and in widths up to 5 ft.

30 • METAL DETECTOR. For detecting metal of any kind in nonmetallic materials such as rubber, limestone, lumber, etc., Eriez Manufacturing Co. is now making a detector which, housed around the material flowing on a conveyor, will actuate an alarm mechanism if tramp metal is present. Can be adjusted for detection of particular sizes, and operates on belt speeds up to 900 ft./min.

31 • SPEEDY FLANGING. For quick pipe-to-tank connections, the American Pipe & Steel Corp. has a new tank flange which can connect pipes to the outside or inside of tanks in only a few minutes. Designed for use with a flanged cutter, the new flange is made up of two pieces—a body and a tightening nut. The flange can be connected either inside or outside of a tank and uses only one gasket. Bulletin available which

states that a 6-in. flange can be installed in 3 min.; smaller sizes in less time.

32 • PNEUMATIC TRANSMITTER. For measuring pressure, vacuum or specific gravity, Instruments Inc. has a new pneumatic transmitter. It employs a forced balance method with a fixed nozzle. High sensitivity, accuracy, are claimed. Uses no levers, pivots, etc.

33 • ARMORED TUBING. A plastic armored metal tubing for conduction of water, air, or gas through corrosive atmospheres, is in production by Samuel Moore & Co. The coating of the tubing can be practically any thermoplastic, and can be made up in any color for coding. Now being made up to 3 in. O.D.

34 • JALLOY. A new special steel for abrasive and impact use is in production and is described in a new bulletin of the Jones & Laughlin Steel Co. It is for use in fabricating of chutes, flumes, balls for pebble mills, wear liners, etc. Bulletin shows many installations, gives table of use, chemical composition, heat treatment, chemical properties and several other pages of technical data which cover hardness, machinability, weldability, etc.

35 • HIGH-VACUUM GAGE. The F. J. Stokes Machine Co. announces a

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| 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 |
| 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | | |

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new nickel McLeod-type vacuum gage with a working range of .05 to 50 mm. Gage was developed to fill a gap between the low range vacuum gages and the dial-type measuring instruments.

36 • PUMP SEALS. Byron Jackson Co. has three new mechanical seals for centrifugal pumps. Designed for sealing stuffing boxes, the company expects them to replace conventional packing in refining, process, and chemical industry pumps. Seals have been installed on shafts from 1½ in. to 5½ in. The seals can be made of synthetic rubber, Teflon, leather, etc. An illustrated 12-page bulletin is available.

37 • STORAGE RACKS. For the interior and exterior storage of drums the Barrett-Cravens Co. has designed a storage rack system which makes any drum immediately accessible when wanted. Made of structural steel the racks are available in 20-drum sections.

38 • MIXERS. A complete redesign of mixers is an improvement announced by the F. J. Stokes Co. The new mixers, available in from 50- to 300-lb. capacity, feature dust-tight lids, variable speed control, adjustable discharge chutes, and perforated troughs to admit solutions.

39 • SCREW CONVEYOR. For better sanitation and prevention of choked materials in screw conveyors, the Screw Conveyor Corp. has developed a new system in which the outside tube as well as the inside screw turns. The outer tube revolves slowly, about 2 rev./min., but the screw itself travels at its normal speed. Of

special interest to food processors and chemical industries where oxidizable materials are required to be conveyed.

CHEMICALS

40 • RESIN GUIDE. For information on the line of resins, surface coatings and printing inks manufactured by American Cyanamid Co., there is now offered a wall plaque with tabbed sheets giving the physical and chemical products of each coating resin. Gives solubility, compatibility, drying schedules, etc.

41 • LABORATORY DETERGENT. Emil Greiner Co. has a surface agent for cleaning laboratory glassware. Designed for laboratory use it is especially effective on grease, and glassware dries without film. Nonionic and stable in the presence of acids and bases, and the polyethylene container is reusable as a laboratory dispenser or wash bottle.

42 • CHLORINE SAFETY CHART. Pennsylvania Salt Mfg. Co. offers a new and durable wall chart on accident prevention and safety measures to be followed in the handling of liquid chlorine. Covers employee protection, leaks, what to do in case of accidents.

43 • ALUMINUM STEARATE. A technical grade of aluminum stearate primarily for the lubricating grease industry, is on the market by Mallinckrodt Chemical Works. Soap costs are reduced through its use and it is pointed toward all industries using aluminum stearates as jelling agents.

A booklet containing descriptions of Mallinckrodt stearates, discussion of manufacturing techniques, advantages, laboratory evaluation of greases, grease plant troubles, etc., is available.

44 • ALKALI DESCALER. Hooker Electrochemical Co. has a new method of descaling steel and iron with a fused alkali bath. Applicable to any metal or alloy not attacked by molten caustic soda at 903° F. Bulletin available.

45 • PROPYLENE GLYCOL. A data sheet on propylene glycol available from Celanese Chemicals. Its physical properties, specifications and suggested uses.

46 • C. P. ION EXCHANGERS. Rohm & Haas Co. announces that for exacting requirements of research workers, it has available analytical grade Amberlite ion-exchange resins. They are supplied in quantities less than 25 lb. and are slated for analytical or theoretical studies. Data sheet available.

47 • DIVINYLBENZENE. Dow Chemical has a technical data bulletin on divinylbenzene. Bulletin contains suggested applications, properties, inhibitors, etc. Of value in industries that can use a self-polymerizable material or one that can copolymerize with other monomers such as styrene.

48 • DYNEL. A folder has been issued by Carbide & Carbon Chemicals Corp. on Dynel, its newest synthetic fiber. It is a staple fiber spun from a copolymer of acrylonitrile and vinyl chloride. Covers properties, suggested uses, characteristics, etc.

49 • SILICATES OF SODA. Diamond Alkali Co. has prepared a 20-page pocket-size manual reviewing its silicate of soda products. Describes liquid grades of silicates of soda commercially available and data supplied with each grade present principal physical properties, major industrial applications, basic advantages, etc.

50 • ORGANIC CHEMICAL CATALOG. Carbide & Carbon Chemicals Corp. has available now the 1950 edition of the book, "Physical Properties of Synthetic Organic Chemicals." It is a condensed guide for users of organic chemicals, contains data on applications and physical properties of organic chemicals.

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Chemical Engineering Progress

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New York



MARGINAL NOTES

(Continued from page 29)

use of the type of data presented and is well worth the modest cost.

Good Reference Book

Organic Reactions, Vol. V, Roger Adams, Editor-in-Chief. John Wiley & Sons, Inc., New York, N. Y. (1949) viii + 446 pp. \$6.00.

Reviewed by A. J. Frey and L. A. Flexer, Vice-President and Senior Chemist, respectively, Hoffmann-LaRoche, Inc., Nutley, N. J.

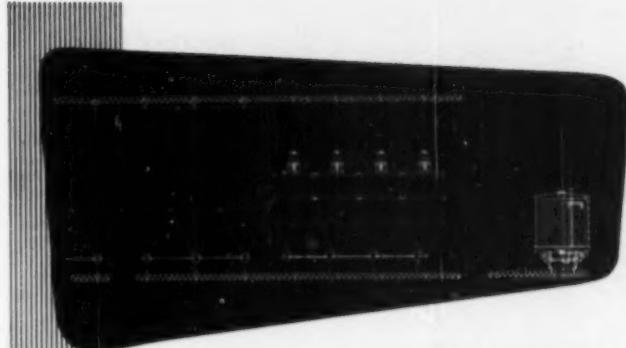
WITH the appearance of Vol. V of this series, Professor Adams has again brought forth a noteworthy contribution to the literature of organic chemistry. As in the previous volumes, important organic reactions are comprehensively covered by different specialists, each reaction comprising a separate chapter. While there is some latitude in the arrangement of the individual chapters, in general each one first defines the reaction under consideration and then treats the subject under such typical headings as Nature or Mechanism of the Reaction, Scope and Limitations, Side Reactions, Experimental Conditions and Procedures, Illustrative Preparations. Perhaps the most important feature of each chapter is the inclusion of complete but easily usable tables showing specific applications of the reaction with yields and literature references.

The subjects and authors of the individual chapters are as follows:

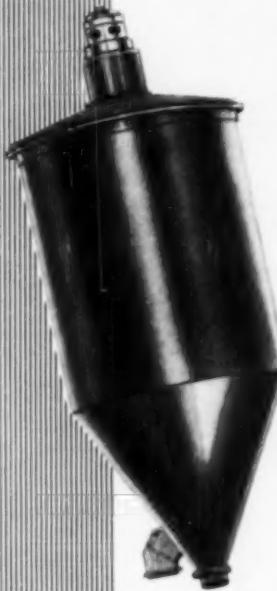
1. The Synthesis of Acetylenes—T. L. Jacobs
2. Cyanoethylation—H. A. Bruson
3. The Diels-Alder Reaction: Quinones and Other Cyclenones—L. W. Butz and A. W. Ryting
4. Preparation of Aromatic Fluorine Compounds from Diazonium Fluoroborates: The Schiemann Reaction—A. Roe
5. The Friedel and Crafts Reaction with Aliphatic Dibasic Acid Anhydrides—E. Berliner
6. The Gattermann-Koch Reaction—N. N. Crounce
7. The Leuckart Reaction—M. L. Moore
8. Selenium Dioxide Oxidation—N. Rabjohn
9. The Hoesch Synthesis—P. E. Spoerri and A. S. DuBois
10. The Darzens Glycidic Ester Condensation—M. S. Newman and B. J. Magerlein

To the chemical engineer interested in any of the above reactions, Organic Reactions vol. V will undoubtedly be a

(Continued on page 33)



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- Bulletin 44 tells the Sprout-Waldron Equipment Story. Write for it today! Sprout, Waldron & Co., Inc., 17 Waldron Street, Muncy, Pa.



120

During the year copies of Volumes 23 and 24 of *The Transactions of The Institution of Chemical Engineers* (London) for the years 1945 and 1946 were distributed to all who were members at the end of these years and therefore entitled to receive these volumes.

Meetings

Four meetings of the Institute were held during the period of this report. The Forty-first annual meeting in New York, Nov. 7-10, 1948, was held at the Hotel Pennsylvania in New York, N. Y. Attendance at this meeting was 2,372; a regional meeting was held in Los Angeles, Calif., March 6-9, at which the attendance was 570; a second regional meeting was held in Tulsa, Okla., May 8-12, with an attendance of 617; a third regional meeting was held in Montreal, Canada, Sept. 6-9 with an attendance of 448. At these meetings 126 papers were presented; many of them have been published in *Chemical Engineering Progress*.

Amendments to the Constitution

At the Business Meeting held during the annual meeting in New York on Nov. 8, certain amendments to the Constitution were submitted for discussion; these dealt with the subject of the number of signatures required for amendment by petition, also some slight modifications in the requirements for Active membership, Associate membership and Junior membership. These were submitted to the membership following the discussion and all amendments were passed by an overwhelming majority.

As a result of the discussion of the above amendments, Council has given considerable study during the year to further modifications in the membership requirements to bring them more nearly in line with the present needs.

Accrediting

The Institute has continued its interest and activity in the accrediting of chemical engineering curricula through its Chemical Engineering Education and Accrediting Committee working very closely with the Engineers' Council for Professional Development. Details of this activity will be covered fully in the report of this Committee.

Awards

At the annual meeting in New York several awards of the Institute, granted annually by the Institute, were presented to the recipients at a special Awards Dinner. The Professional Progress Award in Chemical Engineering was given for the first time. This award is administered by the Institute and is given in recognition of outstanding progress in the field of chemical engineering for the betterment of human relations and circumstances. It consists of \$1,000 and a suitably inscribed certificate. The 1948 recipient was Dr. Allan P. Colburn. The William H. Walker Award which is given to a member of the Institute for outstanding contribution to the literature of chemical engineering went to Kenneth M. Watson. The Junior Award which is granted to that Junior Member or Junior Member of the Institute in recognition of a paper published by the Institute went to J. Edward Vivian and Roy P. Whitney for their paper, "Absorption of Chlorine in Water," which was published in Vol. 43, *Chemical Engineering Progress*.

1950 YEAR BOOK

About April 1, 1950, copy will be prepared and given to the printer for the 1950 edition of the Year Book.

Please check your listing in the current (1948) Year Book to be sure that it correctly lists your address and business connection. If you have not advised the Secretary's Office recently of any desired changes please do so immediately.

In addition to the above awards the Institute sponsors a Student Problem Contest annually. The 1948 award recipients were: First Prize, The A. McLaren White Award—Jack E. Wilber, Clarkson College of Technology; Second Prize—Dale L. Salt, University of Utah; the Third Prize—John William Howard, Jr., Virginia Polytechnic Institute; and Honorable Mention to Lawrence C. Amos, Oregon State College, W. J. Culbertson, Jr., University of Denver and Jack Marion Miller, Oregon State College.

Local Sections

Considerable activity in the local sections of the Institute has been noted during the year. Many of them report considerable increase in membership and meeting activities. A new section has been approved by Council in Kansas City. This brings the total number of local sections to 30 and several applications are pending.

Student Chapters

Interest in the student chapter activities of the Institute has continued and increased during the year. Five new student chapters have been authorized bringing the total number of student chapters to 89. The new student chapters are at the University of California, Catholic University of America, Clemson Agricultural College, Fenn College and University of New Mexico.

One outstanding accomplishment of the committee handling student chapter affairs was the reestablishment of a student publication. Two issues of the Student Chapter News have already been distributed and it is planned that there will be four such issues each school year.

Student Chapter members have been given the privilege of subscribing to *Chemical Engineering Progress* at half the regular subscription rate, namely, \$3.00 per year. About 2,000 students have taken advantage of this opportunity.

Engineers Joint Council

Among the cooperative activities of the Institute is our continued participation with Engineers Joint Council. Our representation has consisted of L. W. Bass, A. B. Newman and D. B. Keyes. The Institute has had representation on the following committees in Engineers Joint Council: General Survey Committee, N. A. Shepard; National Engineers Committee Consultative to Federal Authorities, A. B. Newman and N. A. Shepard; Selective Service Committee, D. B. Keyes and S. L. Tyler; Science Legislation Panel, A. B. Newman; Labor Legislation Panel, W. I. Burt; Committee on Unity of the Engineering Profession, L. W. Bass, who also served as chairman of this committee for a

greater portion of the year; Committee of Engineers Cooperating in Medical Research, A. G. Atchison; Committee on National Water Policy, R. D. Hoak; Committee on International Relations, A. B. Newman. The First Pan American Engineering Congress was held in Rio de Janeiro, July 14-25, 1949, and the Institute Representative was Paul M. Cook.

ECPD

Another joint activity of the Institute is its continued participation in Engineers' Council for Professional Development. Your Secretary has acted as Secretary of ECPD during the year ending Sept. 30, 1949. In addition to accrediting activities referred to earlier in this report ECPD has been active through its committees in the publication of a "Professional Guide for Junior Engineers," "Engineering As a Career," "The Second Mile," and "The Most Desirable Personal Characteristics." Through the Committee on Professional Recognition recommendations to the participating societies have been made concerning uniform grades of membership. The Committee on Engineering Schools has accepted the recommendations for accrediting of the Institute's Chemical Engineering Education and Accrediting Committee and their list, therefore, carries all curricula accredited by this Institute in addition to those in other engineering fields accredited by that Committee. A special committee on Technical Institutes has continued to be active and has added several to the accredited list of technical institutes. Through the Committee on Professional Training considerable progress is being made and publications are anticipated early next year on the subjects of continued education, the engineer in training and professional legislation, and a reading list for Junior Engineers, to mention only a few.

It is with a sense of real loss that the Council reports the passing of the following members: *Active Members*: T. C. Albin, Herbert Austin, A. J. Barnabie, Arthur E. Boss, Walter B. Brown, Willard H. Dow, Andrew M. Fairlie, Charles L. Gabriel, George C. Hale, Merrill E. Hansen, Horace T. Herrick, A. F. Jirous, William C. Kabrich, David R. Kellogg, Thomas L. B. Lyster, C. A. Mann, H. W. Matheson, Lewis B. Miller, A. E. Pardee, M. J. Rentschler, F. E. Stockbach, E. M. Symmes, Lucius M. Tolman, Harry M. Ullmann; *Associate Members*: Clifton L. Lovell, Harry R. Swanson; *Junior Members*: Harry L. Bliss, V. Warren Fox, Richard T. Henrich, Gedaliah Katz, Earl H. Morris, Sidney Schwartzberg and James H. Thomas.

Teller's Report

The Tellers examined the votes cast for candidates for officers and directors of the Institute for the year 1950 and reported their findings to the Council, who declared the following elected:

| | |
|-------------------------------|------|
| President—Warren L. McCabe | 1781 |
| Vice President—T. H. Chilton | 1196 |
| Treasurer—C. R. DeLong | 1757 |
| Secretary—Stephen L. Tyler | 1754 |
| Directors—C. G. Kirkbride | 1243 |
| For 3-yr. term—W. G. Whitman | 1205 |
| For 3-yr. term—G. E. Holbrook | 1071 |
| For 3-yr. term—R. L. Murray | 1071 |

R. L. Taylor, Chairman
G. K. Hickin
H. G. Fogg

MARGINAL NOTES

(Continued from page 31)

valuable reference—possibly the most valuable reference. The tables themselves will be worth the price of the book. On the other hand, the reactions covered are highly specialized and the desirability of vol. V alone for the personal library of the average chemical engineer is questionable. But any reference library worthy of the name should have all five volumes of this excellent series.

New Improved Edition

The Principles of Metallographic Laboratory Practice (Third Edition), George L. Kehl. McGraw Hill Book Co., New York, N. Y. (1949). xiv, 520 pp., 61 tables, 222 figs. \$5.50.

Reviewed by Lincoln T. Work, Powdered Material Research Laboratories, Cambridge 39, Mass.

THE third edition of this work continues the author's original concept of a basic treatment of principles and laboratory practices. Experiments are not included, and are left for the immediate aims of the individual teacher. This edition has been rewritten to include improvements and developments brought about by the war. The book is extensively illustrated. It contains an appendix of eighty-seven pages of tables covering polishing and etching agents, photographic developing formulas, hardness tables, and other essential data.

There are nine chapters: Preparation of specimens for microscopic examination; Etching of specimens for microscopic examination; Metallurgical microscopes and photomicrography; The principles of photography; Macroscopic examination of metals; Hardness testing; Special metallurgical tests; The principles of pyrometry and pyrometric practice; and Thermal analysis.

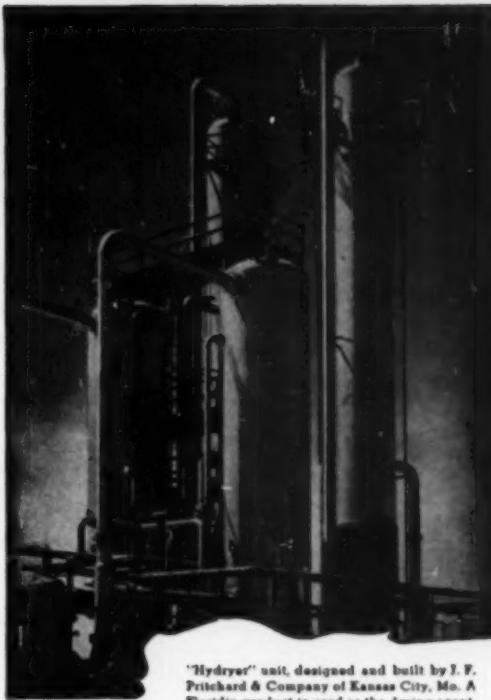
It is well prepared to supplement metallurgical laboratory study. Its treatment should make it useful generally for nonmetallic high temperature practices. In form, printing, choice of paper, etc., the book is typical of the good practices of its publishers. It is recommended for students and workers in the metallurgical and related high temperature fields.

Books Recently Published

Principles and Practice in Organic Chemistry. Howard J. Lucas and David Pressman. John Wiley & Sons, Inc., New York, N. Y. (1949). 558 pp. \$6.00.

The Givaudan Index—Specifications of Synthetics and Isolates for Perfumery. Givaudan-Delawanna, Inc., New York, N. Y. (1949). 378 pp. \$5.00.

Introduction to Semimicro Qualitative Analysis. C. H. Sorenson. Prentice-Hall, Inc., New York, N. Y. 196 pp. (1949). \$2.65.



'Hydryer' unit, designed and built by J. F. Pritchard & Company of Kansas City, Mo. A Floridin product is used as the drying agent.

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LOCAL SECTION NEWS

ST. LOUIS

The November meeting was held in the York Hotel with 75 members and guests in attendance.

During the business meeting reports were rendered by the various chapter committees and at their conclusion the following officers were elected for 1950:

Chairman—J. W. McCrackin, Monsanto Chemical Co.

Vice-Chairman—S. L. Lopata, S. L. Lopata Co.

Secretary-Treas.—C. P. Orr, Monsanto Chemical Co.

Executive Committee—A. B. Kaltwasser, Aluminum Ore Co.; T. J. Stewart, C. K. Williams & Co.

An all-day symposium on some subjects of current interest to chemical engineers is planned for a meeting in the spring.

At the conclusion of the business session two interesting moving pictures were shown. The first film, titled, "Test Tube to Tank Car" told in brief the method used by Monsanto Chemical Co. in developing new organic products. The second film titled, "Curiosity Shop," and prepared by the Aluminum Company of America described some interesting development work on new uses for aluminum which have occurred during the past quarter century.

*Reported by R. S. Yates
and W. O. Lory*

EAST TENNESSEE

The 23rd general meeting was held in the Foremen's Room, Building 89, Recreation Building, Tennessee Eastman Corp., Kingsport, Tenn., Nov. 29, 1949.

The two speakers on the program were Dr. J. E. Vivian, director, school of chemical engineering practice, M.I.T., and Dr. W. A. Reed, director, Oak Ridge station, school of chemical engineering practice, M.I.T. Dr. Vivian's subject "Gas Absorption with Simultaneous Chemical Reaction" was presented as part of the over-all problem of mass transfer. The system, Cl_2 absorption in water, has received considerable study by Dr. Vivian and others, and was used as a basis for developing diffusion equations when reaction takes place. He discussed rate equations based on these diffusion equations for several specific cases. He looked at specific industrial cases and

showed how the equation applied. Dr. Reed explained the purpose of the M.I.T. practice school in general and the Oak Ridge station in particular, and discussed the methods used to accomplish these purposes.

Reported by P. H. Schneider

KANSAS CITY

At the December 13 meeting W. L. Williams, C. F. Braun Co., presented a color motion picture film which his company had prepared entitled "Visual Studies of Action on Bubble Cap Trays." A second film entitled "Bubble Tray Fractionators" prepared by the Standard Oil Development Co. was also shown. Some 50 persons attended the meeting.

At the December meeting the following officers were elected to serve during 1950:

Chairman.....H. M. Hart
Chairman-Elect..Shelby A. Miller
Secretary.....William W. Bodle
Treasurer.....P. R. Duckworth
Executive Committee.Fred Kurata

I. E. Miller

Reported by H. M. Steininger

TENNESSEE VALLEY

Dr. William M. Murray, Jr., director, Southern Research Institute, spoke before this section Dec. 5, 1949. His subject was "The Program of the Southern Research Institute." The meeting was held in the plant cafeteria at the TVA fertilizer works, Wilson Dam.

Dr. Murray traced the growth of that institute since its inception in 1941 by a group of Alabama business men seeking to promote the better utilization of the South's resources by making research facilities and services more accessible to southern industry.

A brief description of the buildings and equipment of the Institute was followed by an account of the few projects completed or now in progress by the Institute. Some projects were the development of an extremely thin tissue from wood wastes, the continuing work on leukemia, a process for making southern cast iron more easily machinable, and the development of a superior peanut butter and peanut ice cream. A number of products and processes developed by the Institute has been placed in commercial use by industry.

Reported by D. O. Walstad

PHILADELPHIA-WILMINGTON

The section met Nov. 15 at Clubhouse Hotel, Chester, with an attendance of 70 for dinner and 105 at the meeting.

Homer B. Seely, project engineer for Howard, Needles, Tammen and Bergendorff, spoke on "The Delaware Memorial Bridge." This four-lane suspension bridge now under construction will have a main span of 2150 ft., making it the sixth longest in the world. Its crossing between points near New Castle, Del., and Deepwater, N. J., over that portion of the Delaware River where the state line is at the low-water mark on the New Jersey shore led to the agreement that Delaware shall have the entire maintenance of this bridge.

C. F. Johnson, manager, Technical Service Committee of Philadelphia, an employment and welfare service sponsored by the Engineers Club with this and other local sections of technical societies, urged the continued cooperation of both employers and applicants in the placement service now being carried on.

The following officers for 1950 were unanimously elected:

Chairman...Dr. Geo. E. Holbrook
*Vice-Chairman*W. Herman Barcus
*Sec'y-Treas.*Richard B. Chillas, Jr.
*Asst. Sec'y-Treas.*Wm. E. Osborn
Executive Committee:

Roy A. Kinckiner
and Wm. E. Chalfant

Junior Representative..David Ross

Reported by R. B. Chillas, Jr.

CHICAGO

C. W. Klassen, chief sanitary engineer, State of Illinois department of Health and also assistant professor in preventive medicine, University of Illinois, addressed a capacity audience on "Industrial Waste Disposal Problems in Illinois" at the November meeting of this section. He summarized the present status of waste disposal and its regulations in Illinois. He predicted possible future requirements and recommendations on optimum policy for an industrial concern on this problem.

The section was proud to learn that one of its members had been given recognition for the best presentation of a technical paper at the Los Angeles Regional Meeting in March, 1949. Melvin J. Sterba won the award with his paper, "Effect of Reactor Temperature on Product Distribution and Quality in Fluid Catalytic Cracking."

Reported by D. A. Dahlstrom

WESTERN MASSACHUSETTS

The third annual meeting was held Dec. 15, 1949, attended by 25 members. This meeting was held for the sole purpose of carrying out business of the section and to elect officers for the next year.

The following were elected for 1950:

Chairman—Charles A. Blaisdell, U. S. Rubber Co., Fisk tire division, Chicopee Falls.

Chairman-Elect—Charles D. Smith, Monsanto Chemical Co., plastics division, Springfield.

Secretary—Howard L. Minckler, Monsanto Chemical Co., plastics division, Springfield.

Treasurer—Robert T. Bogan, Monsanto Chemical Co., plastics division, Springfield.

Executive Committee—Robert L. Brown, Gulf Oil Corp., Springfield.

Reported by Robert L. Brown

DETROIT

A section meeting was held Nov. 29, 1949, at Racham Memorial, Detroit. Dr. Siebert, University of Michigan, presented a talk on "Corrosion in Fluids." Members in attendance numbered 50.

A short business meeting was held prior to the feature talk.

Officers elected for 1950 are:

Chairman..... Thomas Vaughn

Vice-Chairman.... Dwight Miller

Secretary..... Ted Carron

Treasurer..... Leon Chrzan

Reported by Dwight Miller

MINNESOTA CHEMICAL ENGINEERS CLUB

The November meeting of the Minnesota Chemical Engineers Club was a dinner meeting held in St. Paul Nov. 17, 1949. Members present numbered 65. After a short business meeting, Dr. Nelson W. Taylor, assistant director of research, Minnesota Mining and Manufacturing Co., gave a talk on "Ceramic Materials in Chemical Engineering."

Reported by William M. Podas

TULSA

The following men were elected by the Tulsa Section for 1950:

Chairman..... Glen R. Davis

Vice-Chairman.... John H. Eppard

Sec'y-Treas...... Clifton G. Frye

Reported by Frank G. Pearce

DURALOY

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In short, we are staffed and have every facility to serve you on high alloy castings up to 7½ tons, individual casting weight.

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METAL AP

F. B. CORNELL & ASSOCIATES

FUTURE MEETINGS AND SYMPOSIA OF A.I.Ch.E.

Chairman of the A.I.Ch.E. Program Committee

George E. Holbrook

Room 7406 Nemours Bldg.
E. I. du Pont de Nemours & Co.,
Wilmington, Del.

MEETINGS

Regional — Houston, Tex., Feb. 26-March 1, 1950.

Technical Program Chairman: M. C. Hopkins, Pan American Refining Co., Texas City, Tex.

Co-Chairman: K. A. Kobe, University of Texas, Austin, Tex.

Regional — Swampscott, Mass., New Ocean House, May 28-31, 1950.

Technical Program Chairman: R. L. Geddes, Stone & Webster Eng. Corp., Boston, Mass.

Co-Chairman: E. R. Gilliland, Massachusetts Institute of Technology, Cambridge, Mass.

Regional — Minneapolis, Minn., Sept. 10-13, 1950.

Technical Program Chairman: E. L. Piret, Minnesota Mining & Mfg. Co., Minneapolis, Minn.

Annual — Columbus, Ohio, Dec. 3-6, 1950.

Technical Program Chairman: John Clegg, Battelle Memorial Institute, Columbus, Ohio

Regional — Kansas City, Mo., May 13-16, 1951.

Technical Program Chairman: Walter W. Deschner, J. F. Pritchard Co., Kansas City, Mo.

Annual — Atlantic City, N. J., Chalfonte-Haddon Hall Hotel, Dec. 2-5, 1951.

SYMPOSIA

Indoor vs. Outdoor Plant Construction

Chairman: J. R. Minevitch, E. B. Badger & Sons Co., 75 Pitt St., Boston, Mass.

Meeting — Not scheduled.

Authors wishing to present papers at a scheduled meeting of the A.I.Ch.E. should first query the Chairman of the A.I.Ch.E. Program Committee, George E. Holbrook, with a carbon copy of the letter to the Technical Program Chairman of the meeting at which the author wishes to present the paper. Another carbon should go to the Editor, F. J. Van Antwerpen, 120 East 41st Street, New York 17, N. Y. If the paper is suitable for a symposium, a carbon of the letter should go to the Chairman of the Symposia, instead of the Chairman of the Technical Program, since symposia are not scheduled for any meeting until they are complete and approved by the national Program Committee. Before authors begin their manuscripts they should obtain from the meeting Chairman a copy of the Guide to Authors, and a copy of the Guide to Speakers. The first book covers the preparation of manuscripts, and the second covers the proper presentation of papers at A.I.Ch.E. meetings. Presentations of papers are judged at every meeting and an award is made to the speaker who delivers his paper in the best manner. Winners are announced in *Chemical Engineering Progress*, and a scroll is presented to the winning author at a meeting of his local section. Since five copies of the manuscript must be prepared, one should be sent to the Chairman of the symposium and one to the Technical Program Chairman of the meeting, or two to the Technical Program Chairman if no symposium is involved and the other three copies should be sent to the Editors' office. Manuscripts not received 70 days before a meeting cannot be considered.

AKRON

A meeting of this section was held Dec. 8, 1949, at the Elks Club. At this meeting Chairman Paul G. McDermott announced the appointment of Warren Jones as chairman of the local sections committee and Walter Otto as alternate.

Election of Officers for 1950 was also held at this meeting. The following members were elected.

Chairman L. M. Freeman

Vice-Chairman R. C. Stell

Secretary J. W. Kosko

Treasurer W. Harlacher

C. G. Kirkbride, vice-president of research and development, Houdry Process Corp., Marcus Hook, Pa., gave a talk on the Houdry catalytic cracking of petroleum. The latest technique was described, which was condensed by Mr. Kirkbride as follows:

One of the more recent developments in the Houdriflow catalytic cracking technique involves the use of the hydrocarbon charge vapors as the fluid medium in the lifting of catalyst. The major point of application of the vapor lift in the Houdriflow process is in the transportation of regenerated catalyst from the kiln to the reaction zone. This mechanism of catalyst transportation is a supplement to the gas lift method and affords several advantages not realized by former systems of operation. . . It appears that the improved Houdriflow design which utilizes the hydrocarbon charge as a vapor lift will effect a reduction in investment cost of 15 to 20% over the Houdriflow design which utilizes the flue gas as the lifting medium. Also of importance is the fact that the height of the new units would not exceed 150 ft.

Reported by J. W. Kosko

LOUISVILLE

Sixteen members and guests represented this section at the recent Annual Meeting of A.I.Ch.E. in Pittsburgh.

Dr. Frank Berman, Vulcan Copper & Supply Co., Cincinnati, Ohio, addressed the section Dec. 14 on "Commercial Solvent Extractions from Liquids and Solids."

Election of officers for 1950 was held at the December meeting. The new officers are:

Chairman — E. D. Unger, Seagrams

Vice-Chairman — G. C. Williams,

University of Louisville

Sec. & Treas. — H. P. Hansen,

DuPont Company

Executive Committee — H. L. Greene, DuPont Company;

W. R. Barnes, University of Louisville

Reported by H. P. Hansen

NORTHERN CALIFORNIA

At the Dec. 5 meeting of this section the following officers for 1950 were elected:

Chairman—George C. Gester, Jr., California Research Corp., Richmond

Vice-Chairman—Robert W. Lundeen, Dow Chemical Co., Pittsburg, Calif.

Sec.-Treasurer—H. D. Guthrie, Shell Development Co., San Francisco

Executive Committee—C. R. Nelson, Shell Development Co., San Francisco; R. Ward Crary, California Research Corp., Richmond; C. R. Wilke, University of California, Berkeley

The engineering, design, and construction of the Trans-Arabian pipeline were discussed by Sidney P. Johnson, Standard Oil Company of California. A colored motion picture, "The Tapline Story" was accompanied by a running commentary from Mr. Johnson. This motion picture taken over a year ago showed various construction details of the 1,000-mile pipeline from the Persian Gulf across the arid wastes of central Arabia to the Mediterranean Sea.

Of special interest was the Skyhook built at the Ras el Misha 'ab terminal to unload 1,000 tons a day of pipe. Ultimately there will be a refinery at the Mediterranean terminus, but at present the crude is expected to be shipped to Europe for refining. Capacity of the pipeline is 300,000 bbl./day.

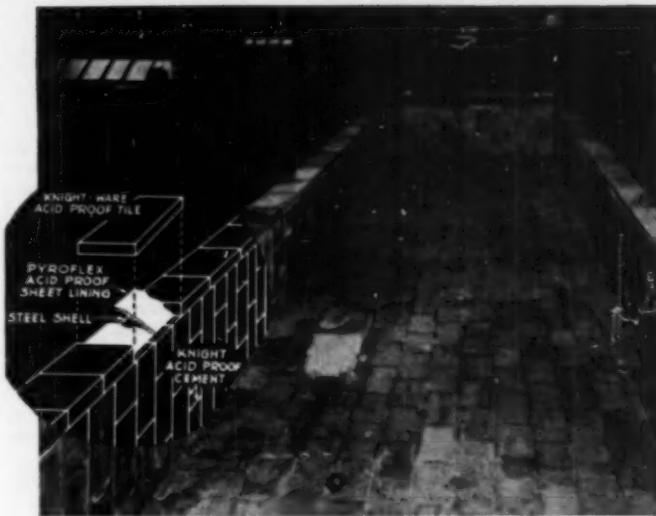
Crude available to the pipeline is 36 to 37° gravity. Most of it is sour so that the hydrogen sulfide will be removed in the field before shipment. Six pump stations are to be located 150 miles apart. At the No. 1 station, centrifugal pumping will be powered by a 6000-hp. steam turbine. Centrifugals at the other five stations will be powered by 6000-hp. supercharged diesels. The entire pipeline is expected to be completed by the end of 1950.

Reported by F. G. Sawyer

BOSTON (ICHTHYOLOGISTS)

Dean William C. White, Northeastern University, and immediate past president, Engineers Societies of New England, addressed this section Dec. 2. His talk covered what engineers can accomplish in technical and public affairs by working together in an organization which includes all engineering societies.

Reported by Henry Avery



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Pickling tanks lead a tough life. The Pyroflex-Constructed Pickling Tank above is in use in a continuous strip steel line in a large Ohio steel mill. It is subject to constant attack by acids, steam and other corrosive agents. To make this tank completely corrosion proof, Knight engineers installed Pyroflex sheet lining heat bonded to the steel shell, then covered with acid-proof Brick set in Knight acid-proof cement. The result is a tank completely resistant to this highly corrosive type of service.

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LOCAL SECTION NEWS

(Continued from page 37)

NEW YORK

A meeting will be held Jan. 18 at the Brass Rail, at 6:30 P.M. G. D. Creelman, director of research, M. A. Hanna Co. will speak on "Interesting Items of Coal Research." His talk will be illustrated with Kodachrome slides. The next meeting will be held Feb. 7, also at the Brass Rail at 6:30 P.M. The speaker will be Dr. Warren L. McCabe, President, A.I.Ch.E., who will discuss the amendments to the constitution concerning changes in the membership requirements. It is urged that section members will refrain from voting on these amendments until after the discussion given by Dr. McCabe.

The annual election of officers for 1950 was held at the meeting Dec. 14, 1949. Declared elected by a majority of those attending were the following:

Chairman—Loren P. Scoville, Jef-
teron Chemical Co., Inc.

Vice-Chairman—W. D. Kohlins,
Bufflovac Equip. Div. of Blaw-
Knox

Secretary—Howard L. Malakoff,
Cities Service Res. & Devel. Co.

Treasurer—Francis B. White, Fos-
ter-Wheeler Corp.

Delegate at Large—Joseph F.
Skelly, M. W. Kellogg Co.

After the election of officers, G. C. Thrift, Koch Engineering Co., discussed Koch Kaskade tray and compared performance data on this tray with those of conventional design.

Reported by R. A. Benzagun

NEW ORLEANS

Officers reelected for 1950 are:

Chairman—Col. Elmo L. Patton

Vice-Chairman—Dr. E. Fred Pollard

Sec'y-Treas.—Henri J. Molaison

Executive Committee:

Harold A. Levey,
Henry Blanchet
and Joseph L. Girodo, Jr.

Reported by Kenneth M. Decossas

CENTRAL VIRGINIA CHEMICAL ENGINEERS' CLUB

The club held a dinner meeting at the Hotel General Wayne in Waynesboro Dec. 2, 1949. Members or guests, present numbered 43. Dr. Worth Wade of American Viscose Corp., spoke on "Patents and Patent Procedures," which was accompanied by slides. Dr. Wade's

talk covered such subjects as the patent group's function in a corporate organization, criteria for patentability, application procedure, rights conferred by patents and finally benefits of and trends in the patent system.

Reported by J. D. Detlefson

OKLAHOMA

New officers for 1950 are:

Chairman John W. Palm

Vice-Chairman Harrison L. Hays

Secretary-Treas. Virgil Scarth

Robert D. Snow

C. R. Ringham as retiring chairman is a member of the executive committee for 1950.

The section met Dec. 14 in the Legion Rooms of the Civic Center in Bartlesville. The attendance included 76 members and guests. Dr. I. A. Anson, Bell Oil and Gas Co., Tulsa, spoke on "The Engineer's Relations to Capitalism, Private Enterprise, and Free Enterprise."

The total registration at the Nov. 12 all-day technical meeting held on the campus of Oklahoma A. & M. College at Stillwater was 205 including 91 students and 18 ladies.

At the banquet K. W. Seed, student at the college presented a humorous technical-type paper on "How to Do Research."

The Women's program included a tour of the Home Economics Building, Women's New Dormitory, Willard Hall Lounge, and attendance at the Horticulture Flower Show.

Reported by George E. Hays

PITTSBURGH

Growth of the "petroleum chemicals" industry was traced by Dr. F. W. Sullivan, Jr., of Madison, N. J., consulting chemical engineer at the Nov. 2 dinner meeting held at the College Club of Pittsburgh. Seventy-nine members and guests were present for the dinner, and a total of 110 heard the speaker's address.

Dr. Sullivan, former research director for Standard Oil Co. (Ind.), and Hydrocarbon Research Corp., respectively, prefaced his address on "Chemicals from Petroleum" with a brief historical outline of the development of the synthetic organic chemicals industry in the United States prior to, and following World War I. Petroleum chemicals have been a strictly U. S. development over the past 25 years.

Reported by Hugh L. Kellner

MARYLAND

This section held recently a joint meeting with the Baltimore Section of the A.S.M.E. at the Engineers' Club in Baltimore for dinner. A talk was given by Dr. H. S. Babcock, Lederle division, American Cyanamid, on the manufacture of antibiotics. He emphasized the chemical engineering aspects of the handling and processing of sterile material and the methods of culture required in the industry.

A meeting was held on Dec. 13 at the Faculty Club of The Johns Hopkins University. Dr. M. C. Molstad, a member of the section and Councilor of the Institute, spoke at length on "The A.I.Ch.E.—Past, Present and Future." He had particularly requested circularization of this meeting among prospective members and students of the university because of the nature of the topic. Several students, both graduate and undergraduate, were present at the dinner and a total of about 15 were present at the talk.

At the business meeting, the following list of officers was elected for 1950:

Chairman.....Dr. W. A. Taylor
Vice-Chairman.....Frank Dehler
Sec'y-Treas.....Alan Beerbower
Executive Committee:

Dr. E. W. Guernsey
Dr. B. L. Harris
Dr. T. H. Manninen

Reported by B. L. Harris

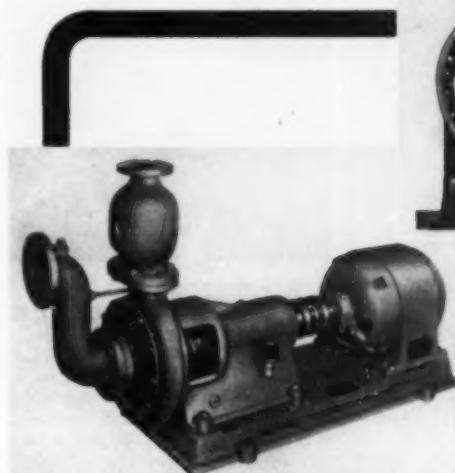
SOUTH TEXAS

A meeting was held in Corpus Christi, Tex., Nov. 18, and was attended by 40 members and guests. The meeting began with an inspection trip through the Corn Products Refining Co. This is a new \$20,000,000 plant which processes milo maize into starch, dextrose, and gluten. From the technical standpoint there were interesting features, especially the instrumentation which reduced almost the entire plant to automatic operation.

The evening part of the meeting was held at the White Plaza Hotel. F. D. Mayfield of the Celanese Corporation of America, Bishop, Tex., spoke on "Waste Disposal." Mr. Mayfield discussed the different types of industrial wastes, and the various means of disposing them. Among other topics, he reviewed the factors affecting the design and operation of evaporation ponds. Of interest was the use of trickling filters employing certain bacteria to convert formaldehyde wastes to harmless effluent.

Reported by W. L. Bolles

(Right) Lawrence Self-Priming Pump exhausting air during priming.



(Left) Lawrence Heavy Duty Self-Priming Chemical Pump.

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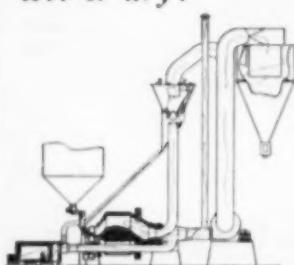


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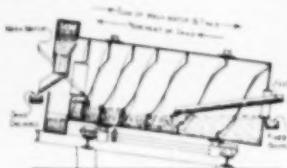


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The Hardinge Loop Classifier can separate a product to 50% or 90% passing 200 mesh. The Hardinge Surface Classifier can produce 99.5% passing 325 mesh. Write for Bulletin 17-B-40 on dry grinding and dry classification.



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The Hardinge Counter-Current Classifier is a simple and trouble-free device for wet separations between 20 and 200 mesh. For finer separation down to micron sizes, a Hardinge Hydro-Separator is used. Write for Bulletin 39-B-40 on wet classifiers.

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PERSONALIA

P. F. PRESTON



**P. F. PRESTON
ADVANCED BY G. E.**

Paul F. Preston was recently named engineering manager, chemical division, General Electric's chemical department. Mr. Preston will continue as manufacturing manager of the division, a position he has held since going to the General Electric in February of this year. Early in his career he was associated

A. S. WOODARD



Albert S. Woodard, acting chief engineer of Pennsylvania Salt Manufacturing Co., Philadelphia, Pa., for the past year, has been named chief engineer, according to an announcement by William F. Mitchell, vice-president in charge of manufacturing. Mr. Woodard joined Pennsalt at its Natrona (Pa.) plant in 1934 and was transferred to the central engineering office in Philadelphia in 1940. He became acting chief engineer in November, 1948. Since that time he has been responsible for the engineering of several major Pennsalt projects, the latest being the company's new Calvert City (Ky.) Works.

The new chief engineer is a graduate of Carnegie Institute of Technology, where he received a B.S. in chemical engineering.

with the Du Pont Company at the Chambers Works in Carney and in the plastics department at Arlington. Subsequently he was named assistant superintendent of the Vinyl resins plant, superintendent of the methyl-methacrylate resins plant and following a year when he was coordinator of postwar planning, he became technical assistant in 1944. Mr. Preston received a B.S. in chemical engineering from Lehigh University.

DIWOKY VICE-PRES. PAN-AM SOUTHERN

Roy J. Diwoky was elected a vice-president of Pan-Am Southern Corp. at a recent meeting of its board of directors.

Mr. Diwoky left an executive position in the manufacturing department of Standard Oil Company (Indiana) last June to join the board of directors of Pan-Am Southern's predecessor company, the Pan American Petroleum Corp. He has been serving and will continue to serve as executive assistant to Pan-Am Southern's president, Bruce K. Brown, at its New Orleans general office.

Mr. Diwoky received his B.S. and M.S. degrees in chemical engineering from the State University of Iowa in 1934 and 1935. He started work with the Standard Oil Company (Indiana) research department in 1935 and rose to group leader in charge of technical service work on crude running, cracking and coking operations. After transferring to the manufacturing department of the Whiting refinery, he served as assistant general superintendent of the light oils division, superintendent of the project division, and assistant general superintendent of the Whiting refinery before transferring to Pan-Am Southern Corp. this year.



R. J. DIWOKY

G. G. BROWN DIRECTOR AEC DIV. ENGINEERING

Dr. George G. Brown, chairman, department of chemical and metallurgical engineering, University of Michigan, has been named director, U. S. Atomic Energy Commission's division of engineering.

G. G. BROWN



Dr. Brown has taken up his duties on a part-time basis and will join the AEC staff on a full-time basis in the spring. As director of engineering, he will be responsible for the chemical engineering phases of the AEC's reactor development program and will work under the general supervision of Dr. Lawrence R. Hafstad, director of AEC's division of reactor development.

Specifically, Dr. Brown will be concerned with the chemical engineering program involved in the establishment and operation of reactors at the new reactor testing station in Idaho and at West Milton, N. Y.; with the development of processes for the recovery of uranium from depleted nuclear fuels, and with the treatment and disposal of radioactive waste matter. While with the AEC, Dr. Brown will be on leave from the University of Michigan.

Dr. Brown was awarded a Ph.D. degree by the University of Michigan. After working with industrial concerns from 1917 to 1920, he joined the faculty of the University of Michigan where he rose steadily, reaching his present position in 1942. Meanwhile, he served in a consulting capacity for several firms.

The new director of engineering was president of the American Institute of Chemical Engineers in 1944 and in 1939 received its Walker Award. He is the author of many technical articles.

V. J. Calise, formerly associated with Liquid Conditioning Corp., and Permutit Co., is now serving in the capacity of technical director, Graver Water Conditioning Co., New York, N. Y.

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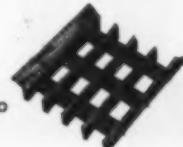


A GRATE with magnetized bars to grab tramp-iron—that's the Bauer Magnetic Grate. The grate is set on a frame in a floor opening or in the throat of a hopper. When bulk materials are dumped, poured, or shoveled in, the grate attracts and holds ferrous chunks and particles which would damage machinery and contaminate the product.

Bauer Magnetic Grates are avail-

able in every practical shape and size from 2" x 4" up to 6 or 8 ft. square. They can be used for demetallizing dry or liquid materials: peanuts, for example, as shown in the photograph.

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Sulfuric acid concentration plant
plagued with costly corrosion. Ap-
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and floors ... in excellent condi-
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Says: "I used to do over on
repairs. Now I'm saving maintenance
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CASE STUDY 73

Muriatic acid plant, fumes eating
out concrete beams and piers. Af-
ter repeated paint failures, used
Prufcoat ... still sound after 6
years exposure. Says: "Extremely
satisfactory. Client extremely ex-
-plesed."

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CASE STUDY 336

NaOH caustic soda carried in tank
cars stripped off every coating
carried previously tried. Finally applied
Prufcoat ... has withstood 8 years
of drips and spills. Maintenance
engineer plans to develop a stand-
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Yes, in plant after plant,
for over ten years now, Prufcoat
has been stopping profit-eating
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maintenance costs—on machinery,
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SITUATIONS WANTED

A.I.Ch.E. Members

Unit Process Engineer—S.C.D., Ch.E., married, 27. Two years' successful industrial experience. Excellent academic record and references. Desire development and research position. Box 1-1.

Chemical Engineer—Ph.D., January, 1950, Columbia University; M.S. & B.E., Johns Hopkins, Age 26, single. Three years' experience, member Sigma Xi, Phi Lambda Upsilon. Desire research and development in organic chemicals. Eastern location. Box 2-1.

Chemical Engineer—Ch.E. Twenty years' experience in plant operation, production supervision, starting new plants, process development and improvement, testing, trouble shooting, laboratory, engineering. Available immediately. Box 3-1.

Chemical Engineer—B.S., 1941. Married, 3½ years organics, chemical processes, petroleum. Full theoretical and practical background. Project engineer for last four years. Desire locate North Jersey, South New York, or Connecticut. Box 4-1.

Chemical Engineer—M.I.T., 1934. Married, family, 18. Broad process and equipment design experience, specifications, instrumentation, operations, maintenance. Professional engineer—Penn. Eleven years one company, head process design division last four. Good publication, patent and professional activity record. Box 5-1.

Chemical Engineer—29, B.S., M.I.T., M.S., Mich. Three years chemical development and engineering in electronics manufacturing. Five years, consulting in process economic analysis, product and process engineering, with design and drafting, and industrial surveys with statistical work in variety of fields. Box 6-1.

Chemical Engineer—B.S.C.E., 1942, Princeton. Eight years' experience. Process development, lab to pilot plant design and operation. A.E.C. project, Q clearance. Production supervision chemical and physical processes. Desire New Jersey Philadelphia area location. Box 7-1.

Active Member—38, B.S.C.E. Fifteen years' experience process and equipment design and development; equipment manufacture, heavy chemicals and plastics. Ten years management level. Desire responsible position with aggressive firm. Box 8-1.

Chemical Engineer—Ch.E., Columbia University. Sixteen years' experience design, construction and operation of equipment for processing plastics, manufacture of synthetic fibers. Aptitude for planning work and report writing. Desire location Eastern U. S. Available now. Box 9-1.

Chemical Engineer—B.C.E., age 30. With proven executive ability. Five years' diversified, plus three years' of refinery and petrochemical process design experience. Serious, responsible worker. Desire opportunity in production with progressive company. Box 10-1.

Chemical Engineer—M.C.E. Unusual proven ability and broad interests. Desire a challenging position with future. Capable of carrying a job through from A to Z. Five years hydrocarbon and atomic energy

fields. Experience includes supervision, coordination, design (chemical and mechanical) of all types of units including allied piping, pressure vessels, instrumentation, etc., and extensive laboratory, pilot plant and plant trouble-shooting. Box 11-1.

Chemical Engineer—B.S., 1939. Interested in problems of small and medium size organizations. Experience in production supervision, design, and line and staff assignments should be valuable to organization planning expansion or modernization or needing personnel capable of immediate contributions and future growth. Box 12-1.

Professor of Chemical Engineering—Head of ECPD accredited department. Twenty years' experience industry and education. Desire similar position in institution offering opportunity to develop graduate study and research, or professorship without administrative duties. Box 14-1.

Nonmembers

Chemical Engineer—D.Eng., Yale 1950, S.M., M.I.T. 1948, Age 24, Tau Beta Pi, Sigma Xi, highest grades. Research in nitrogen oxides cleanup and reaction rates. Desire permanent position in research, development, design in Boston area. Available Summer 1950. Box 16-1.

SITUATIONS OPEN

SALES-ENGINEER NEW YORK DISTRICT OFFICE C. F. BRAUN & CO.

We need a graduate chemical engineer with at least five years experience in Oil Refining. To this man we offer a responsible, interesting, and rewarding position as a member of our New York Office Staff. The work entails some travel. The compensation is straight salary and expenses. And the future is limited only by the man's own ability to produce.

The man we need has technical ability, plus a good personality. On the technical side, our man has a thorough knowledge of heat transfer, fractionation, and of refinery process-design. This knowledge must be based on actual experience. On the personal side, he is between 28 and 35 years old. He is aggressive. He's friendly, and likes to meet new people. And he is sincerely interested in a permanent career in sales engineering with one of the top companies in its field.

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Teacher of Chemical Engineering—Assistant Professor of Chemical Engineering, University of Virginia. Ph.D. desired, for graduate and undergraduate instruction, new building, time and facilities for research, for appointment beginning September, 1950. Box 12-1.

(Continued on page 43)

COLBURN ACTING PRES. UNIV. DELAWARE

Dr. Allan P. Colburn has been named acting president of the University of Delaware, Newark, Del., effective April, 1950. He will serve until a successor is appointed to President William S. Carlson, who has resigned to become president of the University of Vermont.

Since July, 1947, Dr. Colburn has been assistant to the president in charge of research at the university. Previously, he was professor of chemical engineering for nine years and prior to joining the Delaware faculty was with the Du Pont Company for nine years.

In 1936 Dr. Colburn received the William H. Walker Award of the American Institute of Chemical Engineers for his paper, "A Method of Correlating Forced Convection Heat Transfer Data and a Comparison with Fluid Friction."

C. A. THOMAS, A.C.S. BOARD CHAIRMAN

Dr. Charles Allen Thomas, executive vice-president of the Monsanto Chemical Co., St. Louis, and active in atomic energy development, has been elected chairman of the board of directors of the American Chemical Society.

Dr. Thomas was one of the five co-authors of the Acheson-Lilienthal report on international control of nuclear power.

In 1923, he joined the General Motors Research Corp. as a research chemist at Dayton, Ohio, and later became a research chemist on the staff of the Ethyl Gasoline Corp. In 1926, with Dr. Carroll A. Hochwalt, he organized the Thomas & Hochwalt Laboratories at Dayton, specializing in consulting research work for industrial organizations. Ten years later, when the laboratories were acquired by the Monsanto company, Dr. Thomas became central

A. P. COLBURN



research director of the company. He was named a director of the company in 1942.

In April, 1945, Dr. Thomas became vice-president of Monsanto, and in September of that year he was named technical director of the company and a member of its executive committee. He was made executive vice-president in May, 1947, and last October was elected chairman of the executive committee.

Hugo Klein has become vice-president and treasurer, and has been elected to the board of directors, of RC Reproduction Products, 5601 Valley Boulevard, Los Angeles 32, Calif. The corporation manufactures blueprint, diazo-type and other products and equipment for the reproduction industry. He will continue his consulting work as a member of the Association of Consulting Chemists & Chemical Engineers, Inc.

A. C. POPE



Arthur C. Pope was recently elevated to the vice-presidency in charge of manufacturing of the Ansul Chemical Co., Marinette, Wis. Mr. Pope has spent 16 years as production manager of Ansul's sulfur dioxide and methyl chloride plants.

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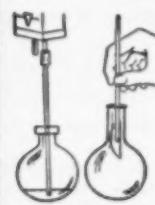
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Each, \$23.75

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(Continued from page 42)

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PERSONALIA

(Continued from page 43)



L. C. STEWART

D. C. Reams, Jr., has joined the staff of the University of Alabama as instructor in chemical engineering. He was formerly at Yale University where he had been an instructor in chemical engineering the past three years.

Joseph J. Schaefer, chemical consultant, has established an office at The Chemists' Club, New York, N. Y. Mr. Schaefer was at one time associated with the Wyandotte (Mich.) Chemical Corp., and with Sharples Chemicals, Inc., Philadelphia, Pa.

Leroy C. Stewart, head of the Washington office of the Dow Chemical Co., since its establishment in 1941 will have charge of a new sales office of the company located at 161 Spring Street, Atlanta, Ga. The area to be served includes Georgia, North Carolina, South Carolina, Alabama, and Florida. A native of Cleveland, Ohio, Mr. Stewart received his B.S. in chemical engineering and his Ch.E. from Case Institute of Technology. He joined the Dow organization in 1918 and has since taken part in production, research and sales development work.

P. J. CARLISLE OF DU PONT RETIRES

Paul J. Carlisle retired Jan. 1 from the Du Pont Company after a career of more than three decades in the chemical industry. For the past four years, Mr. Carlisle has been manager of field research for Du Pont's electrochemicals department.

Mr. Carlisle started his career in 1916 with the Roessler & Hasslacher Chemical Co., Perth Amboy, N. J., which was acquired by Du Pont in 1930. His early work was in the development of a process for the chlorination of methane. In 1918, he was transferred to the St. Albans (W. Va.) plant and was responsible for building and operating a commercial-scale plant there. A year later he was appointed assistant works manager and then works manager, and, in 1921, was transferred to the Los Angeles (Calif.) plant as assistant manager. Five years later, he went to the Niagara Falls plant to organize a research department, and was appointed head of the chemical research department there in 1929, and then manager of the chemical division in 1931. The following year when the Perth Amboy and Niagara Falls research divisions were consolidated, he was made supervisor in charge of cyanide research in the chemical division. From then on, he successively held the positions of assistant director, supervisor of field investigation, manager of the Vinyl products section of the development division, and manager of field research.

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Necrology

EDWARD KIHN

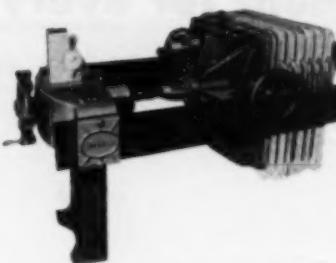
Edward Kihn, an independent chemical engineer, who recently became a member of the Southern California Section of A.I.Ch.E., died Nov. 23, 1949. Mr. Kihn was at one time associated with the Koppers Co., and also served as research chemical engineer with the General Chemical Co.



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The illustration shows a type SW EVACTOR using steam in the first stage and water in the second stage. Here the AQUA-VACTOR is used both as an ejector and as a condenser, handling air and, at the same time, condensing steam from the first stage. Of interest to engineers with corrosion problems, the steam stage in the illustration is constructed of carbon, including the steam nozzle. The carbon is encased in cast iron, giving the equipment the strength of iron and the corrosion resistance of carbon.

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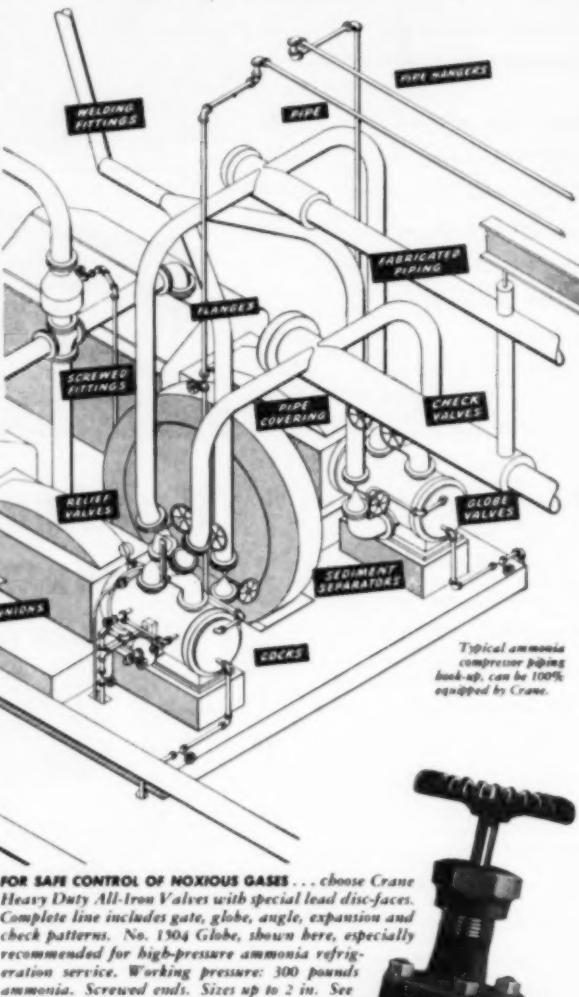
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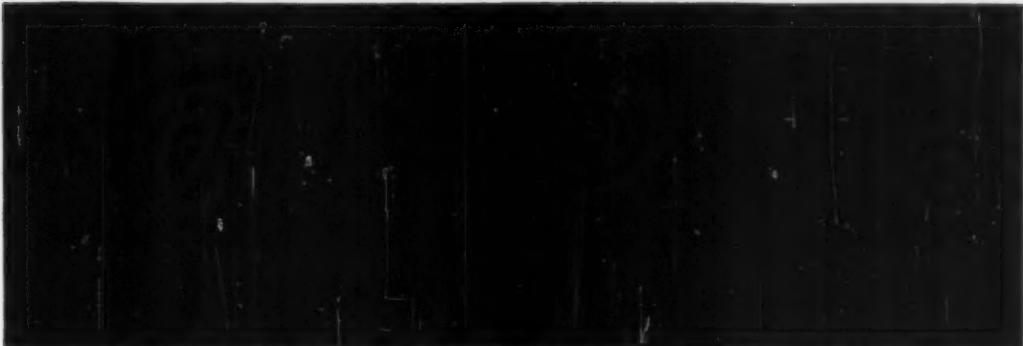
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 D—Combined discharge by plunger one and plunger two. Note the

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Showing drive mechanism, cam tracks, cam follower, etc. Milton Roy "Constametric" Pump. Principles of design and application fully covered by patent applications.



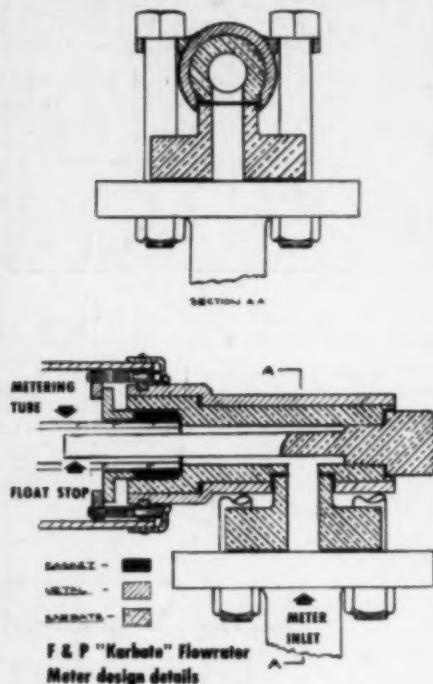
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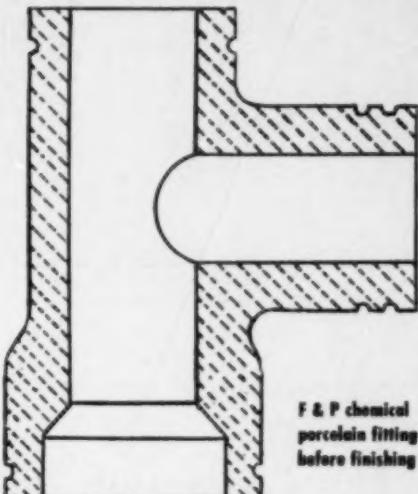
Figure 736
KARBATE
FLOWRATOR METER

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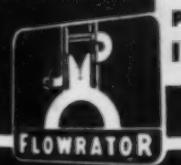
Figure 746
CHEMICAL PORCELAIN
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